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Deaf Children's ASL Vocabulary and ASL Syntax Knowledge Supports English Knowledge

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Abstract

The current study contributes empirical data to our understanding of how knowledge of American Sign Language (ASL) syntax aids reading print English for deaf children who are bilingual and bimodal in ASL and English print. The first analysis, a conceptual replication of Hoffmeister (2000), showed that performance on the American Sign Language Assessment Instrument correlated with the Sanford Achievement Test—Reading Comprehension (SAT-RC) and the Rhode Island Test of Language Structures (RITLS, Engen & Engen, 1983). The second analysis was a quantile regression using ASL assessments to predict English print abilities. Different ASL skills were important for English reading comprehension (SAT-RC) versus understanding English syntax (RITLS); the relationship between ASL skills and English print performance also varied for students at different English print ability levels. Strikingly, knowledge of ASL syntax was robustly correlated with knowledge of English syntax at all ability levels. Our findings provide novel and strong evidence for the impact of ASL on the development of English literacy.

A robust, well-developed first language supports development of a second language in school age children. Despite consensus on this among educators and researchers, the role of signed languages in facilitating Deaf children's access to the majority spoken language, either via spoken language or print, continues to be debated (e.g., Davidson, Lillo-Martin & Pichler, 2014; Hoffmeister & Caldwell Harris, 2014). The current study contributes empirical data to this debate by exploring how knowledge of ASL syntax aids reading English for bilingual bimodal (ASL and English print) students aged 8–18.

Today, more than half of the world's children are raised in communities where multilingualism is the norm (e.g., Marinova-Todd, et al., 2016). Broad agreement exists that multilingualism does not impair acquisition of the societal language and does not cause language disorders (Kohnert, 2007; Novogrodsky & Meir, 2020). Cummins (2006) argued that the linguistic interdependence model is applicable to ASL-English development. That is, knowledge of an accessible language, such as a natural signed language, can scaffold acquisition of speech (Davidson et al., 2014) or the written form of the language (Scott & Hoffmeister, 2017). Diverse data sets have been assembled to support Cummins' claims. These include longitudinal evidence from Lange, Lane-Outlaw, Lange, and Sherwood (2013) and studies showing that signed language supports reading proficiency (Hrastinski & Wilbur 2016, Hoffmeister, 2000, Scott & Hoffmeister, 2017; Novogrodsky, Caldwell-Harris, Fish, & Hoffmeister, 2014 to name a few), and writing proficiency (Wolbers, Bowers, Dostal, & Graham, 2013).

Given that deaf children are usually multilingual and multimodal, thereorists have argued that heteroglossia is useful for characterizing how Deaf children use their multiple languages (De Meulder, Kusters, Moriarty & Murray, 2019; Swanwick, 2017).

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Heteroglossia, comes from the writings of Mikhail Bahktin, a Russian philosopher and linguist. Bahktin argued that enforcing strict boundaries between two languages is politically motivated. In practice, heteroglossia is common, as when bilingual people code-switch and blur the distinctions between languages (Blackledge & Creese, 2014). Heteroglossing appears particularly relevant for Deaf children, who frequently experience several variations of language and communication systems, including artificial and adapted systems. Deaf children may use English or other spoken languages at home with their family, modifications of a signed language (e.g., ASL), home signs, artificial signs, or modified signing systems in the classroom, and native signed languages with their friends and other members of the community. Using several languages, modalities, and systems within the same discourse is *translanguaging*, a topic of scholarly research (Kusters, Spotti, Swanwick, & Tapio, 2017). *Translanguaging* is common for people who live in heteroglossic communities (Schissel, Leung, Lopez-Gopar, & Davis, 2018). Nevertheless, traditional school systems enforce policies of "separate bilingualism", that is, preventing languages from merging or overlapping. Translanguage children may not be fluent in any one language, but still use their language repertoires to scaffold communication to obtain meaning and acquire information as needed (Velasco & Garcia, 2014). The advantage of multiple languages with blurred boundaries is that one kind of communication (such as ASL) may support other kinds of communication (English print reading).

Our contribution to this debate is to investigate this last point: syntactic knowledge in signed language (here, ASL) may support syntactic development of the spoken language and particularly its written versions (here, English). In short, our question is how strongly ASL abilities support reading achievement (Caldwell-Harris, 2021). This was investigated with a school-aged sample of signing deaf children using tasks from the ASL Assessment Instrument (Hoffmeister, Fish, Benedict, Henner, Novogrodsky, & Rosenburg, 2013) along with measures of English reading achievement. To lay a foundation, we summarize the current evidence that ASL supports Deaf children in the acquisition of English via print. The following sections describe how each type of ASL linguistic knowledge, vocabulary, morphology, and syntax facilitate English reading. These types of linguistic knowledge are chosen because they are strongly represented in the chosen American Sign Language Assessment Instrument (ASLAI; Hoffmeister et al., 2013) subtasks used in the analyses.

Vocabulary

Theorists have argued that signed languages cannot support English literacy because of the difference in modality (Mayer & Wells, 1996; Mayer & Trezak, 2020). A key goal of Hoffmeister's (2000) study was to provide evidence to the contrary. Deaf participants, $N = 78$, aged 8–15, were assessed using tests of ASL synonyms, antonyms, rare/infrequent vocabulary, and plural knowledge (distributional and exhaustive forms). Composite scores were used to form an "Intensive" and a "Limited" ASL group of participants. Reading comprehension abilities were measured using scores from the Reading Comprehension subtest of the Stanford Achievement Test (SAT-RC), and the Rhode Island Test of Language Skills (RITLS). The SAT-RC requires participants to answer questions about passages of printed text. The RITLS is a syntax test where an English sentence is given and participants must choose the picture that accurately depicts the sentence. The foil choices depict people or objects doing something similar, meaning syntactic structure must be used to select the target. The RITLS and SAT-RC showed significant, moderate correlations with the ASL composite scores. A subsequent exploration of ASL vocabulary (antonyms) and English reading abilities was carried out with 138 Deaf children (Novogrodsky, Caldwell-Harris, Fish, & Hoffmeister, 2014). Significant correlations were observed between ASL antonym knowledge, measured by the ASLAI (Hoffmeister et al., 2013) and reading scores, measured by the SAT-RC. Although causality cannot always be inferred from correlations, these results indicate a relationship between breadth and depth of ASL vocabulary and a measure of English reading comprehension, consistent with the notion that knowledge in one language supports knowledge in a second language. A multiple regression analysis with antonyms, age, parental hearing status (deaf or hearing parents) and gender (male or female) indicated that antonym knowledge in ASL predicted 35% of the variability of SAT-RC scores. Our findings paralleled those of other studies that found a relationship between ASL lexical knowledge and print decoding skills (e.g., Mayberry, del Giudice, & Lieberman, 2011; Hrsanski & Wilbur, 2017; see also Hermans et al., 2008 for correlations between Sign Language of the Netherlands and Dutch via print).

The ASLAI has also been employed in other studies that examined the link between ASL knowledge and reading comprehension in Deaf children. Scott and Hoffmeister (2017), for example, found that the unweighted mean ASLAI scores, from the analogies, synonym, antonym, plurals, syntax, and rare vocabulary subtests, significantly predicted reading comprehension scores using the SAT-RC and the reading subtest scores of the test Measure of Academic Progress. This maintained even when more variables were added to the regression, including children's use of amplification, race/ethnicity, and word reading fluency.

Morphology

In a recent essay, Bower and Bowers (2018) explain that English spellings have evolved to represent not just sound but also meaning, pointing out the interaction between phonology, morphology and etymology. In signed languages, the relationship between phonology and morphology is a key point of cognitive phonology (see Occhino, 2017 for an explanation). Many handshapes have iconic meaning, points out Occhino.

This is relevant because *meaning* is how skilled deaf readers bridge print and signed language. Trussel and Easterbrooks (2017) noted that in proficient readers, morphological awareness is key to successfully decoding print. Although phonological awareness helps with surface decoding of printed language, morphological awareness enables readers to partition, examine, and understand words based on *meaning* rather than surface features alone. In the case of Deaf children, Trussell, Nordhaus, Brusehaber, and Amari (2018) point out "When reading abilities beyond the fourth grade is the target, morphological knowledge appears to be an essential component of reading and reading instruction" (p. 278). Indeed, excessive instructional emphasis on teaching phoneme-grapheme rules detracts from teaching children how to use morphology to access meaning from print forms. Consistent with this, skilled Deaf readers frequently have good command of English morphology (Clark, Gilbert, & Anderson, 2011).

At present, not enough research connects knowledge of signed language morphology to reading abilities in Deaf children and adults. Clark et al. (2011) gave the ASL Sentence

Reproduction Test (ASL-SRT; Hauser, Paludneviciene, Supalla, & Bavelier, 2008) to 51 adult participants from Gallaudet University. Participants viewed a briefly displayed ASL sentence and had to reproduce it exactly. Adult deaf students with better ASL knowledge had increased English morphological decoding skills. The authors wrote, “Interestingly, students mentioned using signs as a means of decoding novel English words. The spontaneous report of *I don’t know a sign for that* occurred many times while collecting data” (Clark et al., p. 112). From this, the authors concluded that knowledge of ASL often guides English decoding for deaf college students. The authors also measured English phonological awareness. Performance on the English morphological decoding test was related to ASL proficiency scores, but not to English phonological awareness scores.

Morphological knowledge greatly impacts how meaning is displayed in different syntactic structures, which is discussed in the next section.

Syntax

The challenges Deaf children have with syntax of English (or syntax of whatever is the language of school) are well documented (e.g., Lederberg, Schick, & Spencer, 2013; Antia, Lederberg, Easterbrooks, & Webb, 2020; Quigley and King, 1980; see Domínguez, Carrillo, del Mar Pérez, & Alegría, 2014, for Spanish; Niederberger, 2008 for French; Friedmann, Novogrodsky, Szterman, & Preminger, 2008 for Hebrew). Quigley and King (1980) reported that Deaf students had difficulty with the English language structures of negation, conjunction, pronominalization, verb formation, complementation, relativization, and disjunction, and omission of determiners. Note that when we refer to challenges, problems, or *deficiencies* that Deaf children have with syntax, we are using the language used by the hearing authors of the cited articles. We argue that the claim that deaf individuals have syntactic deficits is rooted in racist, ableist discourses.

The challenges with syntax documented by Quigley and others are not found when signing Deaf individuals are tested in a native signed language (e.g., ASL), suggesting that these challenges are not contingent on deafness. Lillo-Martin, Hanson, and Smith (1992) investigated how adult Deaf readers comprehend relative clause structures in print, signed English and ASL. Twenty-six participants were recruited from Gallaudet and separated into good and poor reader groups based on the results of the Gates-MacGinitie Reading Test (1978). Although poor readers struggled with English print, both groups showed adequate understanding of relative clauses in signed English and ASL. Lillo-Martin et al. (1992) argued that deafness is not the barrier to complex syntactic structures; the barrier is lack of access to language. In another study involving complex syntactic structures, native signers had good recall and comprehension of complex syntax compared to late learners of ASL who had lower performance (Mayberry & Eichen, 1991). Moreover, in two previous articles by our team, we demonstrated that early age of exposure is pivotal for developing strong ASL syntax skills (Henner, Caldwell-Harris, Novogrodsky, & Hoffmeister, 2016), and that various factors (e.g., early age of ASL exposure, and disability) impact grammatical judgment abilities in deaf children, similarly to findings from spoken languages (Novogrodsky, Henner, Caldwell-Harris, & Hoffmeister, 2017). In both articles we provided data indicating that early access and exposure was critical to ensure development of a full syntactic system in deaf children.

Syntax and Analogies

There are robust correlations between ASL syntactical abilities and analogical reasoning skills (Henner et al., 2016; 2018). Solving structural aspects of analogies depends on syntactic knowledge (Henner et al., 2018). Knowledge of ASL provided examples of language puzzles, which helped solve the language-based analogies we used in our stimuli. We suggested that the A: B:: C: D word order of the analogical reasoning task was supported by structural knowledge in ASL. Our findings align with both deaf-specific research, such as Cheng & Mayberry (2020), and basic research on analogical reasoning (Gentner & Namy, 2006). For example, even in morphologically rich, flexible ASL structures, the ordering of signs in transitive sentences provides information on who did what to whom (Pichler, 2011). Furthermore, Cheng and Mayberry (2020) found that early exposed L1 signers used word order to understand the meaning of transitive sentences. However, late exposed L1 signers were not able to transfer syntactic knowledge to interpreting ASL analogies. They depended on event probability to interpret the meaning of sentences, which did not help them in solving the task.

To summarize, knowledge in different language domains of sign language (vocabulary, morphology and syntax) is positively related to reading comprehension. It does not matter that the signed language and the printed language are in different languages, in different modalities and have different syntax. In the next section we move to discuss the contribution of replication in research.

The Importance of Replication

Replication of study results are critical for confirming the validity of data-based research (Makel & Plucker, 2014). However, few replications are conducted in the field of education (see Cook, 2014 for a discussion). Replication improves the likelihood that results are accurate (Cook, 2014). The lack of replication indicates that what researchers believe as solid truths within the field may lay on shaky foundations, regardless of the type of inferential statistics used (Amrhein, Trafimow, & Greenland, 2019). Amrhein et al., quoting Fisher (1937), wrote, “Because a small P-value could result from random variation alone, Fisher (1937) wrote that “no isolated experiment, however significant in itself, can suffice for the experimental demonstration of any natural phenomenon.” (p. 262). Without replication, we cannot be sure if many of the *best practices* in deaf education are actually best practices since the low incidence nature of the population studied means that we cannot be sure that the significance of the inferential statistics is not entirely due to chance, nor can we assume that the results can be generalized to every variety of deaf person who on top of being deaf, also has variations in language experience, sex, gender, race/ethnicity, SES, individual skills, and so on. More replication and especially replications with large samples increases conclusion validity and also means that different subpopulations of deaf people will be considered in research.

Cook, Collins, Cook, and Cook (2016) explain that replications can be divided into two types: (a) direct replications and (b) conceptual replications. Direct replications are when methodology and participant characteristics are duplicated from the original study. Conceptual replications occur when attributes of the original study have been changed, to facilitate generalization beyond the sample and method of the original study. Coyne et al. recommended that researchers of specialized education conduct conceptual replications. This has special relevance to

Table 1. Number of participants who took the RITLS by age group and signing status

Age	8	9	10	11	12	13	14	15	16	17	18	Total
Native	13	16	22	28	15	16	26	12	10	10	10	178
Non-native	22	30	36	32	26	29	39	25	37	31	32	339
Total N	35	46	58	60	41	45	75	47	47	41	42	517

Table 2. Number of participants who took the SAT-RC by age group and signing status

Age	8	9	10	11	12	13	14	15	16	17	18	Total
Native	0	0	4	3	2	1	14	8	7	6	6	51
Non-native	3	5	5	8	6	7	4	8	12	12	9	79
Total	3	5	9	11	8	8	18	16	19	18	15	130

researchers of deaf education. Because of early age of inclusion and oral focused education policies, schools and programs for the deaf where studies are often conducted have reduced enrollment (see Valente, 2011 for a discussion).

Using a Large School-Aged Database to Investigate how ASL Vocabulary and ASL Syntax Facilitates English Reading

In our first analysis, we examine the role of ASL vocabulary in ling1uistic transfer by performing a conceptual replication of a study done in Hoffmeister (2000) but with a larger sample population. In Analysis 2, we use the syntactic tests from the same database to investigate the role of ASL syntax in English reading comprehension.

Analysis 1: Replication of the Hoffmeister (2000) Study

Our first analysis is a conceptual replication of the Hoffmeister (2000) study.

Method

Participants. We selected 517 participants from a database established using the ASLAI (Hoffmeister et al., 2013). Of these 517 participants, 178 (34%) were native signers, defined as having at least one parent who is deaf; 339 (66%) were deaf children of Hearing parents. Within the context of language acquisition in deaf children, having deaf parents provides significant weight to the likelihood of native acquisition of ASL. Table 1 presents the breakdown by age and parental hearing status for the participants who completed the RITLS and the ASLAI (see detailed description of the test in the material section) and, Table 2 does the same for the SAT-RC. The data reported was collected from participants aged 7.6–18.5 years old. Because of our focus on reading, selecting students aged at least 7.6 ensured that participants had at least one year of reading experience.

Materials. Two computerized tasks were selected from the ASLAI; also included were the RITLS task (Engen & Engen, 1983) the SAT-RC, all described in the next sections.

ASLAI. The ASLAI is a receptive, computer-based testing battery for measuring ASL knowledge with no English print available. Participants who take the ASLAI sit in front of a computer, and are guided from task to task by a series of structured instructional ASL videos. The general testing format of the ASLAI presents a stimulus, usually an ASL video or in one task a still image (picture of an object), and four subsequent responses presented in ASL. Participants may select a response by clicking on a button. At the end of each task, participants may opt to change their answer after perusing a review panel presenting a video frame of the question and their selections. Tasks within the ASLAI have been normed using classical test theory approaches on over 1,500 participants. At the time of this writing, the ASLAI is the only comprehensive, computer-based test battery for ASL, and it has the largest number of norming participants of any existing signed language-based assessment. The bulk of the data were collected during the 2010–2015 years.

Two tasks were selected from the ASLAI, representing breadth and depth of knowledge of ASL vocabulary and paralleling the task selection from Hoffmeister (2000). All have been described in-depth in other publications and will only be briefly mentioned here. The vocabulary tasks were Antonyms (Novogrodsky et al., 2014) and Synonyms (Novogrodsky et al, 2014). One difference in this replication attempt from the Hoffmeister (2000) study is that one of the tasks, the Plurals assessment, no longer exists in the current iteration of the ASLAI; the Plurals assessment is thus omitted in the current study.

RITLS. Data on participant knowledge of printed English syntax was collected using the RITLS (Engen & Engen, 1983). Although the RITLS is focusing on reading in the sentence level and is not an optimal assessment of print English skills, it a key measure of reading ability in Hoffmeister (2000). Incorporating it into the ASLAI testing system was easy, removing the need for school systems to provide additional data to the research team. An additional advantage is that the RITLS was designed specifically for Deaf and Hard of Hearing children and included norms. The RITLS task was administered by presenting the items via printed English sentences provided in the response sheet. Participants read the English sentences and selected one of three pictures that matched the meaning of the sentence. The vocabulary used in the RITLS is controlled for accessibility by beginning readers. The RITLS may be administered using ASL, English signed systems, spoken English or print. English print is that method of measurement more relevant for our current interest in reading English via print. The RITLS includes 100 questions, divided into 50 simple sentences and 50 complex sentences. Tables 3 and 4 break down the various sentence types that compose simple and complex structures within the RITLS, with

Table 3. Examples of the Simple Sentence Structures in the RITLS from Engen & Engen (1983)

Sentence structure	Example
Pattern 1: Noun phrase, verb	The book fell
Pattern 2: Noun phrase, verb, noun phrase	The girl hit the boy
Pattern 3: Noun phrase, verb, adjective	The boy is happy
Pattern 4: Noun phrase, verb (to-be), noun phrase	The building is a church
Pattern 5: Noun phrase, verb (loc), noun phrase	The boy is in the wagon
Negation	The boy did not eat the apple
Datives	The girl is giving a book to the teacher
Expanded sentences	The boy is picking apples from the trees in front of the house
Nonreversible passives	The ball was thrown by the boy
Reversible passives	The boy was chased by the girl

Table 4. Examples of the Complex Sentence Structures in the RITLS from Engen & Engen (1983)

Sentence structure	Example
Adverbial, main clause first	The dog barked because he had no food
Adverbial, subordinate clause first	Because it was raining the girl played in the house
Relative clause, medial	The woman who is holding the baby has a hat on
Relative clause, final	The man is watching the girl who is in the water
Conjoined clauses	Mother cooked the food and the girl set the table
Deleted structures	The boy ate his lunch but the girl didn't
Noninitial subject	The one who is calling the boy is the girl
Embedded imperative	Open that door!
Complements, subject	Father's washing the dishes made mother happy
Complements, object	Father wants the dog to go out

examples of each structure taken from the RITLS manual (Engen & Engen, 1983). Each sentence structure is represented by five items.

Sat-RC. Data on reading comprehension was collected using the SAT-RC (Traxler, 2000) and provided by the schools where the participants were enrolled.

Results Hoffmeister (2000) grouped participants by intensive and limited ASL experience. We replace these categories with native and non-native, respectively. The first analysis done by Hoffmeister compared the means of the two groups on each test using a simple T-Test, with the result of higher reading achievement in deaf students with intensive ASL experience. We replicated this using our dataset and provide an adapted side by side version of the Hoffmeister (2000) results (Table 5). All means provided come from the dataset that included the 517 participants, with the exception of the SAT-RC means, which as stated earlier had 130 participants.

The correlations of each of the two ASLAI vocabulary measures (synonyms and antonyms) with English reading comprehension (SAT-RC) are almost identical across the 16 year gap in time, with r values ranging from $r = 0.51$ to $r = 0.54$, considered moderate-to-strong relationships. In contrast, the correlation between ASLAI vocabulary measures and English syntactic ability (RITLS) were $r = 0.36$ and $r = 0.39$ in 2000, but $r = 0.62$ and 0.65 in current data. That is a sizable change across the 16 years; the relatively low sample size of the 2000 data means r values are less reliable. However, the increase in r values only occurred for correlations with the RITLS, opening up the possibility that the ASL-RITLS relationship has changed between the two time periods. This data can be seen in Tables 6 and 7.

Discussion: Analysis 1

Hoffmeister's (2000) analysis was important for showing that English reading comprehension (SAT-RC) and English syntax structure (RITLS) increased linearly with ASL ability. However, many educators and researchers urged for more evidence before accepting that signed language facilitates English literacy (Moores, 2010). In the 20 years since, additional studies have reported connections between signed language abilities and print literacy (e.g., Hermans, Knoors, Ormel, & Verhoeven, 2008; Novogrodsky, Caldwell-Harris, Fish, & Hoffmeister, 2014; Scott & Hoffmeister, 2017; Hrastinski & Wilbur, 2016, among others). The consistent conclusion of these studies is that ability in signed language facilitates reading in the school language (here, English). This supports the idea of language blurring and heteroglossia discussed earlier. A strong language foundation is critical for strong language skills in another language, regardless of modality. As Hall, Hall, and Caselli (2019) remind us, Deaf children need *language*, not just speech (see discussion in Caldwell-Harris, 2021).

Our goal with this first analysis was to replicate the original Hoffmeister (2000) study which tested 50 children, 21 native signers, and 29 non-native signers. Our replication used 517 participants from RITLS dataset, including 178 native and 339 non-native signers, and 130 from the SAT-RC dataset including 51 native and 79 non-native signers.

We were able to conceptually replicate the Hoffmeister (2000) study and its results. Native signers outscored non-native signers on the synonyms and antonyms assessment in both the 2000 study and the most recent dataset (2018). The most critical Hoffmeister (2000) result was that native signers outperformed non-native signers on measures of reading comprehension and English syntax. Similar results were also identified in the 2018 dataset analyzed for the current study. However, we stress that these results do not mean that native signers are superior because they are native. Deaf children with at least one deaf parent are likely to have accessible communication and accessible language at home. Hearing parents who do not sign can learn to sign and provide accessible environments for their children (see Caselli, Pyers, & Lieberman, 2021). Therefore, we argue that it is language access at home (to sign language) rather than the native/non-native status of signers that contributes to the higher scores on reading comprehension and English syntax.

We have several ideas regarding the higher RITLS scores in the current data compared to Hoffmeister (2000). One could speculate that more consistent use of ASL in contemporary bilingual Deaf classrooms allows some individuals to acquire high levels of ASL ability, including syntactic ability, which then transfers to greater understanding of English syntax. The current

Table 5. Background, age, ASL tasks, reading tasks (means)

	Present study (RITLS | SAT-RC)			Hoffmeister (2000)		
	Native ($n = 178$ | 51)	Non-native ($n = 339$ | 79)	p-value	Native ($n = 21$)	Non-native ($n = 29$)	p-value
Age	12.46 | 14.7	13.16 | 14		12.3	12.1	
Synonyms	74.0	53.0	$p < .001$	69.5	43.9	$p < .001$
Antonyms	71.0	51.3	$p < .001$	65.0	48.0	$p < .01$
RITLS ($n = 178$)	81.5	72.8	$p < .001$	84.6	74.9	$p < .05$
SAT-RC ($n = 51$)	650.3	601.9	$p < .001$	592	548	$p < .05$

Table 6. Correlational data from Hoffmeister et al. (2000) dataset

Task	SAT-RC	Synonyms	Antonyms	RITLS
SAT-RC	1			
Synonyms	0.51**	1		
Antonyms	0.54**	0.66*	1	
RITLS	0.38*	0.38*	0.36*	1

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

Table 7. Correlational data from the recent ASLAI dataset

Task	SAT-RC	Synonyms	Antonyms	RITLS
SAT-RC	1			
Synonyms	0.55***	1		
Antonyms	0.52***	0.73***	1	
RITLS	0.62***	0.64***	0.65***	1

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

data have a larger range of ASL abilities, with some participants continuing to have poor ASL ability due to language deprivation in the visual modality, but there is also an increased pool of students with very good ASL ability, due to recognition of the importance of signed languages. This might lead in the future to increased range of scores (i.e., the opposite of restricted range), which can result in increased r values. This is consistent with the explanation of increased range of RITLS scores in the current data, which showed that the RITLS correlated with SAT-RC at $r = 0.62$ in the current data compared with $r = 0.38$ in Hoffmeister (2000).

We also cannot discount those changes in how the assessments were administered may have influenced the score changes. In 2000, the ASLAI was a videocassette/pen-and-paper assessment, and the RITLS was also pen-and-paper. The ASLAI and RITLS are currently administered using a proprietary computer-based platform. The video quality is better with computer-based interface compared to the older VHS version. Lim, Ong, Wilder-Smith, & Seet (2006) demonstrated that people seem to prefer computer-based assessments over pen-and-paper, and this seemed to be true of the current assessment interface compared to the prior pen-and-paper experience. Improving how participants interact with the assessment means that the assessment is less of a barrier for assessing participant skills in the targeted construct. This could also explain why the ASLAI average scores increased slightly compared to Hoffmeister (2000).

Analysis 2: The Impact of ASL Syntax Knowledge (L1) on SAT-RC (L2) and RITLS (L2) Scores

Method

Participants. The same deaf students included in the conceptual replication done in analysis 1 (not the participants from Hoffmeister, 2000) were included in the second analysis (see Table 1).

Analysis. Vocabulary, syntax, and analogical reasoning skills were used to predict reading comprehension. Vocabulary was measured using the same Antonym and synonym tasks, averaged into a single variable. Two syntactic tasks from the ASLAI were also combined into a single measure, these were syntactic judgment and sentence-picture matching. Additionally, the ASL Analogies task was also included. This task uses five types of analogical relations: (a) causal, (b) antonym, (c) whole-part, (d) noun verb pairs, and (e) ASL phonology—type analogies.

Quantile regression was carried out with the quantreg package in R (Koenker, 2018). A quantile regression is statistically preferred when a dataset is not normally distributed. Quantile regression is similar to a multiple regression, but differs in using medians rather than means; analysis on medians is more robust to non-normality. Non-normality in our dependent measures, English reading abilities, occurs due to clustering of scores at the low end of the distribution of scores. A sizable minority of deaf children have a history of language deprivation (for more details see Henner et al., 2018), which frequently depresses reading ability (Mayberry, 2007; Humphries, Kushalnagar, Mathur, et al., 2014).

Quantile regression also allows us to analyze how strongly different independent variables influence outcomes for different sections of the reading ability distribution. The independent variables may influence participants in the lowest quantile differently that participants scoring in the highest quantile.

We did not include signing status in the modeling because Novogrodsky et al. (2014) and Henner et al (2017) showed that when ASL knowledge is strong, the impact of signing status (native versus non-native) is minimal. Additionally, Henner et al. (2017) demonstrated that non-native children exposed early to signed language and those who participate in signing environments acquire strong ASL skills. The focus of the current analysis is not on the effects of early signed language exposure, but on how *strength of ASL language (L1) skills* predicts success in comprehending *English print (L2)*.

Results Table 8 shows results organized according to quantiles, here called tau. The tau quantiles represented the 25th, 50th, 75th, and 90th quantiles. The left side of Table 8 shows SAT-RC as the dependent variable; right-sided columns in Table 8 shows results using the RITLS. Note that the quantile groups for SAT-RC and RITLS may be composed of different participants as not all students took both of these English comprehension tasks. Also, being in the 25th quantile for SAT-RC scores does not necessarily mean being in the 25th quantile for RITLS. The regression reported in Table 8 only lists the most powerful predictor (unique variance).

In the 25th and 50th quantile, only Age and Analogies predicted performance on the SAT-RC. For the RITLS, ASL vocabulary, syntax, and analogies significantly predicted the test scores. In the 75th and 90th quantile, only Analogies predicted results on the SAT-RC. For the RITLS, in the 75th quantile, ASL Vocabulary and Syntax skills predicted the test scores. In the 90th quantile, Age and ASL Syntax predicted RITLS scores. These results are summarized in Table 9.

Discussion: Analysis 2

Having conducted the conceptual replication from Hoffmeister (2000), we went a step further from correlations and analyzed the data using quantile regression. We demonstrated that ASL syntax mediated performance on an English reading comprehension test, and on a test of understanding English syntax in print. How strongly ASL syntax predicted English ability depended on the English test construct and the English skills of the participant. In this discussion, we start with the results of the reading comprehension, where the SAT-RC was the dependent variable, and then we discuss the results of English syntax, measured by the RITLS.

SAT-RC For the SAT-RC, which is a reading comprehension measure, only two variables predicted the results; Age and ASL Analogies. Age predicted SAT-RC scores for the 25th and 50th quantiles, but not the 75th and 90th quantiles. ASL Analogies predicted SAT-RC scores for every quantile.

Age is a known factor in improved reading abilities because maturation increases cognitive abilities in the areas critical to reading, particularly working memory, inference, and general conceptual knowledge (Chiappe, Hasher, & Siegel, 2000). These factors are important in boosting reading comprehension in our sample for students in the bottom half of reading ability. Age may still be a factor among stronger readers, but analogical reasoning abilities are more important than age for those in the upper-half of the reading ability distribution.

Analogical reasoning scores in ASL influenced English reading comprehension at every ability level. ASL vocabulary, which indicates conceptual knowledge, is presumably integral to reading comprehension, so why were ASL vocabulary scores not significant predictors in the regression? ASL vocabulary is generally correlated with reading, as we showed in Analysis 1, Table 7. Reading English also requires syntactic skills. Why was ASL syntax also not significant? Performance on the ASL analogies task requires and is correlated with both ASL vocabulary and syntactic knowledge (Henner et al., 2018). The current result suggest that analogical reasoning ability was the variable associated with the most unique variance in reading comprehension.

But is there an additional angle to the question of why analogical reasoning ability is crucial for reading English texts? The role of analogies in reading acquisition has been studied in hearing children by Goswami and Mead (1992). However, Goswami and Mead focused on how children use analogies to parse words at the phonological level, by parsing structures of onset (the initial consonants) and rime (the first vowel and following phonemes) in decoding printed words. We suggest that analogical reasoning skills help Deaf readers figure out the meaning of unknown words in the text, and to perform additional inferencing skills necessary in reading challenging texts. It makes sense that these skills help at every ability level, since the SAT-RC was administered to a wide age-range in our study. Thus, it is possible that at every ability level test-takers were confronted with words they do not know. Successful reading comprehensions therefore benefits from the ability to infer word meaning from context (Krashen, Lee, & Lao, 2017).

Analogical reasoning can help readers relate word meaning, including roots of words, and syntactic factors like the order of the words in the sentence (Gentner & Namy, 2006). Analogical reasoning can help any reader who encounters text pitched at the edge of or outside their ability level, but is especially necessary for deaf readers who frequently encounter unknown English words in print. For deaf students to become successful readers they must apply skills that lie at the intersection of analogical reasoning, morphological and syntactic knowledge, and extent and depth of vocabulary knowledge. This intersection is the crossroads where the use of contextual skills becomes highly advantageous.

RITLS The RITLS is a test of English syntax that our team used when collecting ASLAI data to ensure that all participants had at least one English-based assessment that was the same across testing sites. The most salient result is that knowledge of ASL syntax predicted knowledge of English syntax for every quantile. The finding that knowledge of ASL syntax facilitated performance on a test of English syntax seems on the one hand obvious, but has important implications, as we discuss in more detail below. Here we discuss reasons for the pattern of other predictors.

The RITLS was designed to measure knowledge of English syntax independently of vocabulary knowledge; to achieve this, test designers avoided complex vocabulary. Nonetheless, the knowledge of word meanings is crucial for using syntax to choose the correct picture target. Consistent with this, ASL vocabulary facilitated achievement on the RITLS for all but those students in the 90th quantile. However, analogical reasoning was only important for students in the lowest ability quantile. This is a striking difference from what was observed in the SAT-RC. Gentner and Namy (2006) proposed that analogies help children figure out sentences when they are less proficient in a language. Strength in analogical reasoning may primarily help individuals who lack sufficient English syntactic skills to infer answers to RITLS items (see Cheng and Mayberry, 2020). The benefits provided by analogical reasoning abilities are not as critical to those with stronger English ability (i.e., those at higher quantiles) yet they are available if needed. We suspect this is due to the forced-choice nature of the RITLS. A sentence is presented, then three pictures are displayed, and participants must choose the correct picture representing the stimuli sentence. For students who already know some English syntax (i.e., those above the 25th quantile), picture choice may not require analogical problem solving.

Age was a significant predictor of RITLS scores for the 90th quantile. Age has typically been a weak predictor in other publications based on data from the ASLAI (e.g., Henner et al., 2016; 2018) because deaf children's reading can be poor even into middle childhood and the teen years, due to language deprivation among other factors. This results in language ability being more important for predicting English reading than age. That age is a predictor for the 90th quantile points to a role for skills that accompany cognitive maturity. Likely skills responsible include meta-linguistic knowledge, general knowledge and test-taking

Table 8. Regression analysis ASL knowledge (vocabulary, syntax and analogies based on the ASLAI measures) as predictors of reading comprehension and English syntax via print. (Significant scores are highlighted in light gray.)

	SAT-RC			RITLS		
	Beta	Standard error	T-value	Beta	Standard error	T-value
0.25 (**tau**)						
Age	4.42	1.93	2.29*	0.003	0.002	1.39 (n.s.)
Vocab	61.61	33.74	1.82 (n.s.)	0.15	0.06	2.39*
Syntax	60.91	48.20	1.26 (n.s.)	0.43	0.07	5.53***
Analogies	71.22	28.86	2.47*	0.25	0.07	3.78***
0.50 (**tau**)						
Age	5.45	2.15	2.53*	0.003	0.002	1.67 (n.s.)
Vocab	46.91	37.69	1.24 (n.s.)	0.15	0.04	3.50***
Syntax	78.55	54.57	1.44 (n.s.)	0.37	0.06	6.11***
Analogies	84.57	33.31	2.53*	0.11	0.05	2.08*
0.75 (**tau**)						
Age	3.35	2.15	1.56 (n.s.)	0.002	0.001	1.38 (n.s.)
Vocab	33.00	36.84	.89 (n.s.)	0.13	0.03	3.99***
Syntax	32.05	53.96	.59 (n.s.)	0.25	0.05	4.44***
Analogies	108.64	31.55	3.44***	0.06	0.04	1.50 (n.s.)
0.90 (**tau**)						
Age	4.40	2.34	1.88 (n.s.)	0.004	0.001	2.85**
Vocab	25.76	40.34	.64 (n.s.)	0.07	0.03	1.85 (n.s.)
Syntax	8.15	55.22	.14 (n.s.)	0.15	0.05	2.80**
Analogies	90.06	38.32	2.35*	0.05	0.03	1.32 (n.s.)

Note. For space reasons, we have collapsed the p-value column into the T-value column using asterixis. $p < .001 = ***$, $p < .05 = **$, $p < .01 = *$

Table 9. Summary of the ASL predictors for English reading (SAT-RC) and knowledge of English syntax (RITLS) in the four quantile groups

Quantile	SAT-RC	RITLS
25th	Age, analogies	Vocabulary, syntax, analogies
50th	Age, analogies	Vocabulary, syntax
75th	Analogies	Vocabulary, syntax
90th	Analogies	Age, Syntax

strategies (e.g., scrutinizing all options before choosing a picture as the answer). Future work could investigate those RITLS items which are only successfully answered by persons in the 90th quantile, to explore the student characteristics of the older top performers.

Implications for research and teaching Our findings have considerable implications for future research and teaching.

How and when does age and its associated factors correlate with different English skills in deaf students? Age was correlated with English passage reading for students in the bottom half of the passage reading distribution, but was correlated with ASL syntactic knowledge for students in the upper quantile of syntactic ability. Maturity brings gains in world knowledge, working memory, and inference. Which of these is responsible for these different effects? Or is some other factor responsible which is correlated with age, such as test-taking ability?

Why were analogical reasoning abilities so helpful for deaf child's English passage reading, as measured on the SAT-RC? The unusual difficulty of learning a language via print suggests that proficiency will be helped in "all hands on deck manner" (Caldwell-Harris, 2021). Diverse skills will need to be recruited, including problem-solving, inferencing, and strategies consistent with heteroglossia. As we described earlier, learners may be using analogical reasoning to learn new words encountered during reading. Alternatively, analogical reasoning may be correlated with other unmeasured abilities, such as general intelligence. Future experiments can investigate this question.

Should analogical reasoning be taught? Analogical reasoning helps all readers navigate difficult texts and supports learning language while reading (Gentner & Namy, 2006; Krashen et al., 2017). Does explicitly teaching deaf children ASL analogical reading improve reading skills? Or is it sufficient to teach English standard inferencing skills specific to reading? Is there an advantage to teaching either of these skills in L1-ASL versus L2-English? Future experiments can definitely answer this question.

Theoretical implications Several of our results are novel and relevant to key questions in deaf education. Knowledge of ASL syntax was correlated with knowledge of English syntax for students at all ability levels, spanning students from 7 to 18 years of age. Also striking was how analogical reasoning in ASL was associated with English reading at every ability level. These results are strong support for cross-linguistic, cross-modality transfer (Meir & Novogrodsky, 2020) in the domains of reading and understanding English syntax.

Our findings contribute to the larger question of how ASL skills facilitates English literacy. One longstanding explanation is that learning ASL reduces and forestalls language deprivation in deaf children, allowing normal cognitive development (Humphries et al., 2014). An additional advantage of ASL as a first language is that ASL can be used to explicitly teach English as a second language (Caldwell-Harris, 2021; Koulidobrova, Kuntze, & Dostal, 2018). These have considerable face validity, but suggest that overall ASL competence will broadly facilitate English literacy. In contrast, our findings are pointed: Analogical reasoning ability in ASL is specifically correlated with English reading test scores, but not correlated with English syntactic test scores (excepting the lowest quantile of students). ASL syntactic skills are specifically correlated with English syntactic abilities, but not with reading of text passages. The specificity of our findings is what indicates cross-linguistic, cross-modality transfer of skills.

Given our evidence that deaf test takers drew on ASL knowledge when taking an English test, our results support the relevance of heteroglossia to deaf language learning (De Meulder, et al., 2019; Swanwick, 2017). A key idea of heteroglossia is that multilingual people become skilled in exploiting their multiple languages in the service of communication. This can be especially crucial when learning various languages and modalities, as is often the case for deaf children. Signed, spoken, and written languages can facilitate each other because all language formats draw from the same semiotic pool, allowing meaning to be consistent and portable across languages and modality (Hodge, Ferrara, & Anible, 2019). As an example, in a study of story retellings from an Auslan corpus of 40 narratives, Hodge et al. identified a variety of strategies that ensured comprehension between languagers. Cross-modality strategies included gestures, pointing, English mouthing, fingerspelling, and of course signing. The semiotic diversity within the corpus provided evidence for the blurred boundaries between languages and modality.

Another example of cross-modality effect is shown in Stamp et al. (2021) who compared simple sentence production in three languages: Palestinian Arabic in speech, Modern Standard Arabic in writing, and Israeli Sign Language in signing by deaf students in an Arabic-speaking community. Focusing here only on the productions of the deaf participants (who were also compared to hearing students), the results showed that they omitted more direct-objects (while incorporating them in the verb using classifiers) than other lexical parts and more in ISL, which also affected the production in spoken and written Arabic.

Our results support the importance of early signed language exposure for deaf children (Hall et al., 2019). Having a signed language as an L1 is an essential developmental stage prior to learning to read. Acquiring fluency in signed language as an L1 that supports age-appropriate cognitive and social development and can be used for learning English as an L2 via print (Hoffmeister & Caldwell Harris, 2014; Mayberry & Eichen 1991). Access to language is access to funds of knowledge. Access to funds of knowledge allows learning to proceed along predictable developmental paths, supporting learning L2 and learning about the world. The blurred boundaries between languages and modalities means more opportunities for deaf children and adults to manage their language resources and improve both as they become better at interacting with nonsigners.

The results also support the importance of replication in deaf education research. Our conceptual replication of Hoffmeister (2000) provided stronger evidence of his findings of a relationship between ASL skills and print English skills. In the present day, these results provide evidence for cross-transfer between languages of different modality and support bilingual education.

The field of deaf education should move beyond questioning if bimodal education is good for deaf children and instead focus on improving teaching bilingual/bimodal teaching methods so that deaf children have the same opportunities as hearing children.

Conflicts of Interest

The authors report no conflict of interest.

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