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The Development and Evaluation of a New ASL Text Comprehension Task

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Being able to comprehend a language entails not only mastery of its syntax, lexicon, or phonology, but also the ability to use language to construct meaning, draw inferences, and make connections to world knowledge. However, most available assessments of American Sign Language (ASL) focus on mastery of lower level skills, and as a result little is known about development of higher-order ASL comprehension skills. In this paper, we introduce the American Sign Language Text Comprehension Task (ASL-CMP), a new assessment tool to measure ASL text comprehension ability in deaf children. We first administered the task to a group of deaf children with deaf parents ($n = 105$, ages 8–18 years) in order to evaluate the reliability and validity of the task, and to develop norms. We found that the ASL-CMP has acceptable levels of internal consistency, difficulty, and discriminability. Next, we administered the task to an additional group of deaf children with hearing parents ($n = 251$, ages 8–18 years), and found that the ASL-CMP is sensitive to expected patterns: older children have better ASL text comprehension skills, literal questions are generally easier to answer than inferential questions, and children with early exposure to ASL generally outperform those with delayed exposure. We conclude that the ASL-CMP task is reliable and valid and can be used to characterize ASL text comprehension skills in deaf children.

Keywords: ASL, assessment, comprehension, deaf, sign language

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INTRODUCTION

Reading comprehension—the ability to extract meaning from a text, to evaluate that information, to draw inferences, and to make connections to outside information—is an essential skill for classroom learning, as well as for later academic, social, and occupational achievement (Duke and Pearson, 2002; Shanahan, 2005; Van den Broek and Espin, 2012; Ciullo et al., 2016). In 1994, The New London Group proposed a theory of multiliteracies (first published in 1996), which broadened the understanding of literacy to encompass the ability to engage with many forms of text. In a rapidly-evolving world of information and technology, they argued that texts encompass both traditional formats like essays, articles, or books, but should also consider forms such as speeches, blogs (Shema et al., 2012; Mackey and Jacobson, 2014), vlogs (Griffith and Papacharissi, 2009), graphic novels (Jimenez et al., 2017), and online reading (Leu et al., 2015). With a broadened definition of text, literacy can be considered as a constellation of skills through which a person can extract and construct meaning from these various forms.

ASL Texts

In parallel with these expanded definitions of text and literacy, some began to consider compositions in sign languages as a form of text, and the ability to engage with these compositions as a form of literacy (Kuntze, 2004; Kuntze et al., 2014; Wall, 2014). We embrace this reimagining, and use it as a framework to examine the complex linguistic and cognitive skills involved in engaging with passages composed in American Sign Language (ASL)[1], which we will refer to as ASL texts.

We define an ASL text as a composition expressed in ASL that is used to communicate information to others (Christie and Wilkins, 1997; Byrne, 2015). Although typically ASL is ephemeral, in the way that spoken language "disappears" once it is produced, signers can also of course record their own productions. ASL texts may be produced live, as in a lecture or presentation, or may be recorded by video or other medium (e.g., motion capture) or generated digitally (e.g., avatars). The form of ASL texts most analogous to a conventional understanding of written texts are signed videos that have been designed deliberately, often involving multiple iterations of editing and refining, and are recorded such that users can preview, review, and engage with them repeatedly. ASL texts can be classified into a host of literary genres, including poetry (Christie and Wilkins, 1997; Blondel et al., 2008), satire (e.g., Hearing Knows Best [https://youtu.be/MoxVdw6T0LA] by Malzkuhn and Bottoms, 2017), fiction, jokes, and stories (Bahan, 2006; Byrne, 2015). Non-fiction ASL texts have become prevalent in recent years with the establishment of several ASL news outlets that produce news stories of particular relevance to deaf people or about the world at large (see The Daily Moth [https://www.dailymoth.com] by Abenchuchan, 2019 and Sign1News [https://sign1news.com] by Jones, 2018). Additionally, some museums have installed ASL expository texts adjacent to each exhibit that offer ASL users access to self-guided tours (Martins, 2016). A more popular, generally less edited, example of an ASL text is the vlog, a short video message of one or two signers expressing an opinion or short narrative that is often shared through social media. Given the large and growing body of text available in ASL, it is critical to understand and evaluate how deaf children develop the ability to engage with this material (Snoddon, 2010).

Like all texts, ASL texts can be important sources of information through which people can expand their knowledge, skills, and experience. Additionally, by learning to comprehend an ASL text in their primary language, deaf students can gain familiarity with various genres, develop the ability to interpret explicit and implicit meaning, and make connections to prior knowledge or other texts (Kuntze, 1998, 2004; Kuntze et al., 2014), which in turn contributes to later reading comprehension (Duffy, 2009). These modality-general skills are important not only for engaging deeply with ASL texts, but many scholars have proposed that ASL texts provide an entry point to engaging with written English (Hoffmeister, 2000; Bailes, 2001; Kuntze, 2004; Cummins, 2006; DeLana et al., 2007; Kuntze et al., 2014). While comprehension of ASL text in deaf children has been, to our knowledge, underexplored, we expect that many of the same skills identified for written text comprehension underlie ASL text comprehension.

Text comprehension relies on a host of language and literacy skills. At a basic level, comprehending a text entails lower-level language skills including identifying words and parsing sentences (Perfetti and Stafura, 2014; Silva and Cain, 2015). In addition to these basic skills, higher-order skills are needed to integrate information explicitly stated in the text as well as information implied by the text (Pettit and Cockriel, 1974; Bishop and Adams, 1992; Cain and Oakhill, 2007). This requires the use of prior knowledge, and the ability to construct a coherent interpretation of the text including drawing conclusions and making predictions (Kintsch, 1998; Nassaji, 2003; Perfetti et al., 2005; Cromley and Azevedo, 2007; Landi, 2010).

Better understanding the development of ASL text comprehension is of particular interest for deaf children because the majority of deaf children are at risk of limited language proficiency and low literacy levels (Hrastinski and Wilbur, 2016). Deaf children do not have auditory access to all of the sounds of speech, and even with the best-available technology and interventions their spoken language outcomes are variable and often poor (Manrique et al., 2004; Bouchard et al., 2009; Niparko et al., 2010; Peterson et al., 2010; Ganek et al., 2011; Dettman et al., 2016; Kral et al., 2016; Szagun and Schramm, 2016; Humphries et al., 2017). At the same time, more than 90% of deaf children have hearing parents who do not know a sign language at the time the child is born (Hall, 2017; Hall et al., 2018), so in addition to incomplete access to spoken language, deaf children also often have limited exposure to a sign language during early childhood. For all these reasons, it is critical to assess whether or not children have developed the complex language and literacy skills involved in engaging with an ASL text.

Existing Assessments of ASL Comprehension

Despite the importance of higher-order text comprehension skills, existing ASL assessments generally focus on basic proficiency in ASL vocabulary and grammar, and there is currently no means of evaluating the more advanced skills that are necessary for ASL text comprehension. Currently available ASL tests include, for example, the American Sign Language Vocabulary Test [ASL-VT; (Mann et al., 2016)], the MacArthur Bates CDI for American Sign Language (Anderson and Reilly, 2002), the ASL-CDI 2.0 (Caselli et al., 2020), the ASL Phonological Awareness Test (ASL-PAT; McQuarrie and Spady, 2012), the American Sign Language Proficiency Assessment [ASL-PA; (Maller et al., 1999)], the ASL Receptive Skills Test (Enns and Herman, 2011), ASL and Non-linguistic Perspective Taking Comprehension Tests (Quinto-Pozos and Hou, 2015), and the Visual Communication and Sign Language Checklist [VCSL, (Simms et al., 2013)]. See Haug (2008) for an overview of available ASL assessment tests. These tests predominantly focus on lower-level language skills including phonology, vocabulary, morphology, and syntax, rather than higher-level text comprehension skills. One exception is the American Sign

[1]Our focus in this paper is on American Sign Language, though the approach would largely generalize to compositions in other sign languages.

Language Assessment Instrument (ASLAI; Hoffmeister et al., 2015), which includes sub-tasks that assess ASL analogical reasoning (Henner, 2015), and ASL complex syntax (Hoffmeister et al., 2015). Another exception is the Test of American Sign Language [TASL, (Prinz et al., 1994; Strong and Prinz, 1997)], which probes deaf children's comprehension of ASL text as a set of literacy skills, but has not been evaluated for psychometric quality nor are there developmental norms (Haug, 2008). To our knowledge there is no currently available normed assessment that evaluates deaf children's comprehension of ASL text.

The Current Study

In the current study, we present a new assessment of ASL text comprehension called the ASL Text Comprehension task (ASL-CMP). The goal of the ASL-CMP is to measure ASL text comprehension skills among deaf children. We first describe the development of the ASL-CMP, and present an evaluation of its psychometric properties in a sample of deaf children who had access to ASL from birth. Following the psychometric evaluation, we present results from a larger sample of deaf children that included both those with deaf parents and hearing parents. The goal of the larger sample was to test three primary predictions:

1) We expected that, because they generally have earlier exposure to language, deaf children who have deaf parents would outperform deaf children who have hearing parents in accuracy on the test (Hoffmeister, 2000; Goldin-Meadow and Mayberry, 2001; Berke, 2012; Henner et al., 2016). Because the age of onset of ASL acquisition is generally correlated with language proficiency (see Mayberry and Kluender, 2018 for a review), we also expected that age of entry into a school that uses ASL would be negatively correlated with ASL text comprehension among children who have hearing parents.
2) We predicted that accuracy on the ASL-CMP would increase during childhood and adolescence, as is generally found in studies of written text comprehension (Barnes et al., 1996; Cain and Oakhill, 1999; Nippold and Scott, 2010).
3) We predicted that accuracy would be higher for questions assessing literal comprehension than for those that required children to make inferences, as inferential comprehension is generally more difficult than explicit text comprehension (Pettit and Cockriel, 1974; Johnston, 1984; Miller and Smith, 1985; Bowyer-Crane and Snowling, 2005; Cain and Oakhill, 2007).

METHODS

Development of the Assessment

The ASL-CMP was created by a team of deaf native-signing linguists and educators and hearing linguists who are familiar with ASL. Deaf experts who have technical expertise as well as mastery of the language play a critical role in ensuring validity of ASL assessments (Hoffmeister, 1988; Paludneviciene et al., 2012; Hoffmeister et al., 2015; Enns et al., 2016; Henner et al., 2018). The ASL-CMP was developed as a subtest of the ASLAI, a large, comprehensive, norm-referenced ASL assessment. The ASLAI has been used to test receptive ASL skills in Deaf children from ages 4–18 years across the United States (Henner et al., 2018). The ASLAI evaluates a wide range of linguistic properties of ASL, such as vocabulary, syntax, and analogical reasoning skills (Hoffmeister et al., 2015). All tasks in the ASLAI, including the ASL-CMP, are administered via computer and are multiple-choice. All questions and answer choices are presented in ASL, and formatted with consideration of the linguistic demands of ASL, as described in the section Test Procedures.

Test Content of the ASL-Text Comprehension Task

The ASL-CMP consists of three ASL texts that were adapted–not translated–from texts in two different reading assessments: the Qualitative Reading Inventory-5 (QRI-5), an informal reading assessment used to identify students' reading levels (Leslie and Caldwell, 2011) and the Houghton Mifflin Reading Assessment (Houghton Mifflin, 2010), a research-based diagnostic reading assessment. In contrast to test translation where the goal is a sentence-by-sentence match between the original and translated version, our goal in adapting these tests was to create texts that had an overall conceptual match with the original but the words, sentences, and structure of the text were free to differ (Hambleton and Patsula, 1998; Van de Vijver and Poortinga, 2005).

The English texts that served as the models for the ASL texts were titled *Bridges, Photosynthesis*, and *Marva Finds a Friend* (Leslie and Caldwell, 2011). The English texts were originally designed for children ages 8–12 years. Two of the English texts (*Bridges* and *Photosynthesis*) are expository, non-fiction texts, and the third (*Marva Finds a Friend*) is fiction. Texts were selected based on the target age range, and because they contained a straightforward sentence structure, which enabled adaptation to ASL (e.g., no passive voice and simple sentence structure). The three adapted ASL texts and English translations of those texts are available at https://osf.io/dwhba/. The length of the ASL texts were 2 min, 39 sec (*Bridges),* 1 min, 36 sec (*Photosynthesis*), and 2 min, 58 sec (*Marva Finds a Friend).* Each ASL text was followed by five multiple-choice questions. Three of the questions were related to information that was explicitly mentioned in the text (literal questions) and two of the questions were related to information that was implied by the text but not explicitly stated (inferential questions). Further, each set of five questions was consistent in structure such that there were two WHAT questions (one literal, one inferential), two WHY questions (one literal, one inferential), and one WHICH question (literal). The foils for each question were all ASL signs and consisted of two related but incorrect answers, and one unrelated answer. For literal questions, the related foils differed from the correct answer in either verb or subject in ASL. For example, if the correct answer was GIRL *WALK SEE* OLD HOUSE[2], related but incorrect answers used the verb *RUN* or *BIKE* instead of *WALK.* For inferential questions, the correct answer included information that must be deduced from the text. For example, in one of the ASL texts a girl sees a ghost and runs away. One of the questions asked why the girl ran away and the correct answer

[2]Since ASL is not a written language, we use standard glossing conventions (i.e., capital letters) to represent ASL signs.

can be translated to, "She is scared." This is a plausible inference based on the text, but not explicitly stated. The three foils are less plausible explanations for her behavior (e.g., "she escapes because she is late for school," "she likes to run," or "because a dog chases after her").

The first draft of the ASL-CMP was piloted with a group of seven deaf, linguistically-trained, ASL-English bilingual adults who were not part of original task development. Target accuracy for the adult participants was 85% or higher (i.e., at least six out of seven participants selected the correct answer) for each question. Three questions (one literal and two inferential) did not meet this criterion, suggesting they were either unclear or too difficult. The pilot participants were also asked to evaluate the quality of the ASL texts for clarity and grammaticality of signing production. In this process, one video was identified that was not appropriately edited (i.e., it had extended pauses and jump cuts). The problematic questions and text were then modified: the questions that did not yield high accuracy were replaced with new questions and one video was re-filmed for fluidity. We then re-tested the same participant group, at which point all questions were answered with 85% accuracy or higher. Finally, to confirm that questions were appropriately labeled as literal and inferential, all of the questions were evaluated by three teachers of deaf students with a master's degree in either deaf education or ASL who were unfamiliar with the test. There was 100% agreement in the classification of the questions as literal and inferential.

Test Procedures

Participants were recruited to take the ASL-CMP as part of a large-scale study involving the ASLAI assessment battery (Hoffmeister et al., 2015). All of the language tasks in the ASLAI, including ASL-CMP, were self-administered by participants on a computer. Prior to each of the sub-tests, participants watched an instructional video in ASL (see Henner, 2015; Hoffmeister et al., 2015). The instructions encouraged children to try their best when answering the questions on the test. The students then began a practice section that included one short ASL text and three questions (two literal questions and one inferential question). The students were given feedback on the practice trials. The ASL-CMP test questions immediately followed this practice. For each text, children first viewed the ASL text, and then saw a screen with the first question. Each question screen contained six different small videos consisting of the ASL text on the bottom left, the question on the top left, and the four different answer choices on the right in a two-by-two grid (**Figure 1**). The participants were instructed to watch the question, click on each of the four answer videos, and then select whichever video they thought best answered the question by clicking on the relevant video screen. To reduce working memory load, the question screen and four answer screens showed a carefully selected image as a frozen frame when the videos were not playing. Each frozen frame contained a salient feature of an ASL sign that could help the participant remember the contents of the video (Hoffmeister et al., 2015). For example, the question screen might contain a frozen frame of a wh-question, and the answer choices might contain an image of a critical sign. The ASL text was included on the screen to allow the participants to review the ASL text if needed. In addition to the frozen frames, there was no time limit and participants could re-watch the ASL text, the questions, and possible responses as many times as needed. The ability to review the entire text at will is an important feature that distinguishes the current task from a listening comprehension task, in which the information "disappears" after it is presented. In the current task, akin to a reading comprehension task, participants could refer back to parts or all of the story as they were determining their responses to the questions. All of the participants' responses were automatically scored and saved on a server. Scoring was dichotomous: participants received one point for a correct response and zero points for an incorrect response.

Participants

All of the participants in the present study were recruited through Boston University's Center for the Study of Communication & the Deaf (CSCD). All participants were deaf children attending schools for the deaf where ASL was the primary language of instruction. Participants varied with regard to when they were first exposed to ASL, as well as their ethnicity, hearing ability, IQ and age of entry to school. All participants that were able to complete the test were included in the sample.

For the psychometric evaluation of the ASL-CMP, only participants that had deaf parents were included ($n = 105$). These participants were chosen because of their homogeneity of age of exposure to ASL (i.e., all were exposed to ASL from birth). These participants had an age range of 8–18 years ($M = 11.2$ years).

The second set of analyses include an initial evaluation of the ASL-CMP among a wider group of deaf children. For these analyses, participants included the above sample of deaf children who have deaf parents ($n = 105$), plus an additional group of deaf children with hearing parents ($n = 251$) between the ages of 8–18 years ($M = 12.6$; see **Figure 2**). The sample was racially and ethnically diverse: of the 356 participants, there were 185 White, 49 Hispanic/Latino, 26 African American, 16 Micronesian, 19 Filipino, 15 Asian, 22 other, and 24 did not report. Information about age of entry into a school for the deaf was available for a subset of participants ($n = 202$). Of these, children with deaf parents ($n = 48$) entered school between birth (i.e., via early intervention) and 9-years-old ($M = 3.62$ years), and children with hearing parents ($n = 154$) entered school between 1 year and 18 years ($M = 7.12$ years).

RESULTS

Psychometric Analysis of the Normative Sample

All analyses were conducted with the statistical software R. Psychometric analysis focused on the consistency and reliability of the test questions. We first used item response theory (IRT) to determine discrimination (how well an item differentiates between high- and low-skilled participants) and the level of difficulty of each question in a standardized test (Yang and Kao, 2014). In contrast to classic test theory, IRT considers both individual participants and individual items which provides greater sensitivity about the items in relation to

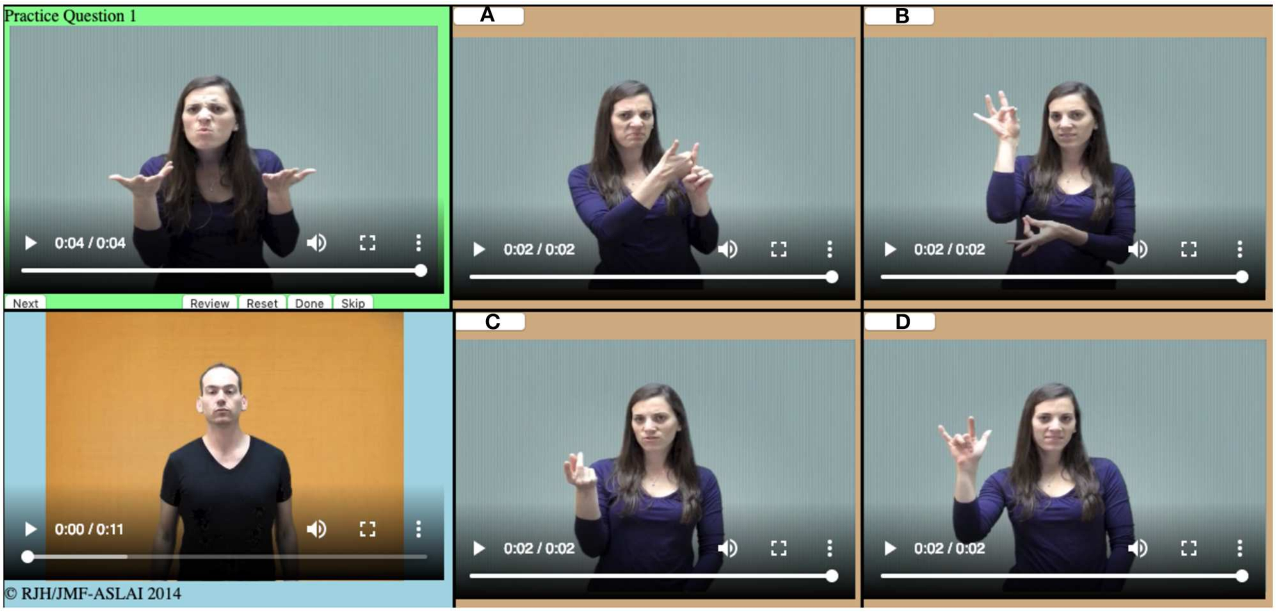

FIGURE 1 | Sample screenshot of one test question. The top left panel is the comprehension question, with a still image of the sign WHAT. The bottom left panel shows the ASL text, which participants will have already reviewed, but is available for review as students make their answer. The four panels on the right are each of the answer choices, with a button labeled with a letter that corresponds to their answer choice. **(A)** SELF; **(B)** GHOST; **(C)** DOG; **(D)** AIRPLANE. Written informed consent was obtained from the individuals in this image.

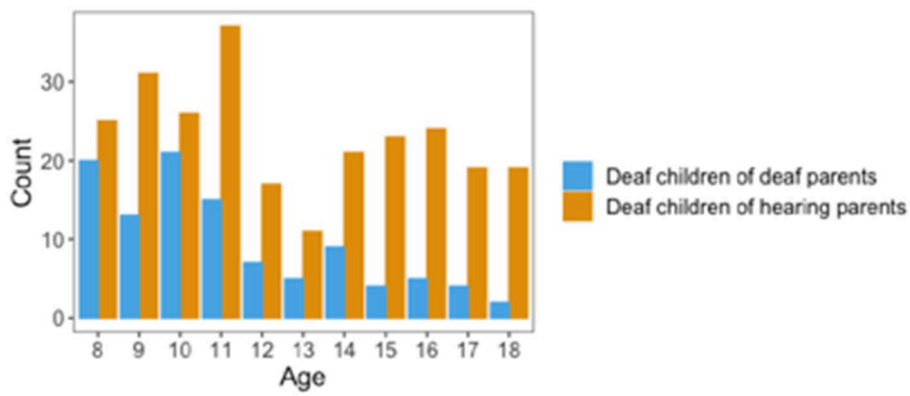

FIGURE 2 | Number of participants with deaf parents ($n = 105$) and hearing parents ($n = 251$) at each age.

individual abilities. Items with a discrimination value of 0.20 or above are considered acceptable, while values below the 0.20 threshold do not sufficiently discriminate between the skilled participant and the unskilled participant (Baker, 2001; Taib and Yusoff, 2014). The acceptable range of difficulty for each question is 0.20 and 0.80 (Baker, 2001). Values below 0.20 indicate that the question is too difficult, and above 0.80 indicate that the question is too easy. In general, questions that do not meet the criteria for both discrimination and difficulty should be revised or deleted (Ebel, 1954; Baker, 2001). As presented in **Table 1**, results from the IRT analysis indicated that all of the questions in the ASL-CMP test except for two literal questions had acceptable discrimination power and appropriate range of difficulty. These questions were removed.

In addition to item response and discrimination, we assessed internal consistency among questions on the task. We initially computed Cronbach's alpha of the ASL-CMP across all questions, which revealed an acceptable internal consistency of alpha 0.80. To determine consistency within each type of question, we also computed Cronbach's alpha separately for questions that assessed literal and inferential comprehension as two different, but related, constructs. We used a criterion of an alpha of 0.70 or greater, which indicates that the items are measuring the same construct (Santos, 1999; Tavakol and Dennick, 2011). We removed the two

TABLE 1 | Item difficulty and discrimination of the questions in ASL-Text Comprehension Task.

Question #	Type of question	Mean (*sd*)	Item difficulty	Item discriminability	A if deleted
1	Inferential	0.61 (0.49)	0.61	0.56	0.62
2	Literal	0.73 (0.44)	0.73	0.30	0.68
3	Literal	0.57 (0.50)	0.57	0.34	0.67
4	Literal	0.71 (0.45)	0.71	0.45	0.65
5	Inferential	0.47 (0.50)	0.47	0.30	0.71
6	**Literal**	**0.50 (0.50)**	**0.50**	**0.19**[a]	**0.70**
7	**Literal**	**0.22 (0.42)**	**0.22**	**0.04**[a]	**0.72**
8	Inferential	0.73 (0.44)	0.73	0.53	0.64
9	Literal	0.71 (0.45)	0.71	0.42	0.66
10	**Inferential**	**0.47 (0.50)**	**0.47**	**0.25**	**0.73**[b]
11	Literal	0.76 (0.43)	0.76	0.55	0.63
12	Literal	0.72 (0.45)	0.72	0.56	0.63
13	Literal	0.66 (0.48)	0.66	0.51	0.64
14	Inferential	0.71 (0.45)	0.71	0.61	0.61
15	Inferential	0.72 (0.45)	0.72	0.42	0.67

[a]*Denotes unacceptable discriminability value.*
[b]*Denotes change in alpha when removed.*
Bold row denotes omission in the final analysis.

literal questions in addition to one inferential question that did not meet the criteria (described above). The Cronbach's alpha for the final set of seven literal questions was 0.75 and for the five inferential questions was 0.72. Thus, the final version of the ASL-CMP, consisting of 12 questions, had acceptable levels of internal consistency (alpha = 0.85), discriminability, and difficulty.

Next, we evaluated concurrent validity by determining the relationship between the ASL-CMP and two other ASL vocabulary tests from the ASLAI, ASL Antonyms (Novogrodsky et al., 2014a) and ASL Synonyms (Novogrodsky et al., 2014b). Both of these tests used the same format as the ASL-CMP, and both tests asked students to select from a set of four different signs that best matches the given sign, synonymously or antonymously. We conducted Pearson correlation analyses for performance on the ASL-CMP and the two ASL vocabulary tasks in the ASLAI (Hoffmeister et al., 2015). Scores on both vocabulary tests were positively and significantly correlated with scores on ASL-CMP (antonyms: $r = 0.76$, $p < 0.001$; synonyms: $r = 0.74$, $p < 0.001$).

Finally, we used quantile regression to create growth charts of deaf children with deaf parents on the ASL-CMP (**Figure 3**). There was an increase in accuracy on the ASL-CMP with age, and an apparent ceiling effect at 12 years.

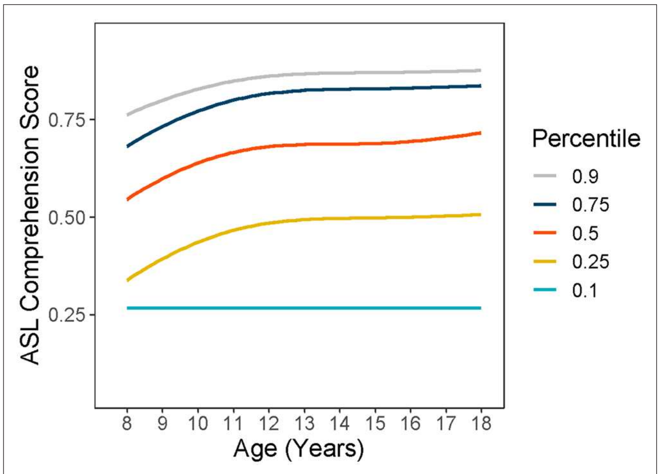

FIGURE 3 | The relationship between age and accuracy on the ASL-CMP for deaf children with deaf parents ($n = 105$). Lines indicate the 10th, 25th, 50th, 75th, and 90th percentiles, and were generated using the gcrq function in the R package quantregGrowth. The graph is not intended to be used to classify children's performance as within/above/below the normal range.

Evaluation of the ASL-CMP in Deaf Children With Deaf Parents and Deaf Children With Hearing Parents

Following the initial psychometric analysis, we assessed performance on the revised ASL-CMP on a larger group of participants, including children with deaf parents and those with hearing parents ($n = 356$). If the test is sensitive to differences in age and amount of language exposure, then we would expect to see higher accuracy in deaf children who have deaf parents vs. deaf children who have hearing parents, higher accuracy in children with hearing parents who entered school early vs. those who entered school late, and higher accuracy in older vs. younger children. We also predicted that accuracy would be higher for literal than inferential questions. **Figure 4** illustrates overall performance by age and participant group. Performance for deaf children with hearing parents shows greater change with age than for deaf children with deaf parents.

To analyze performance, we conducted a mixed-effects logistic regression using accuracy as the dependent variable (correct = 1, incorrect = 0; **Table 2**). In our initial model (Model 1), the fixed effects were participant group (deaf children who have deaf parents, deaf children who have hearing parents), age

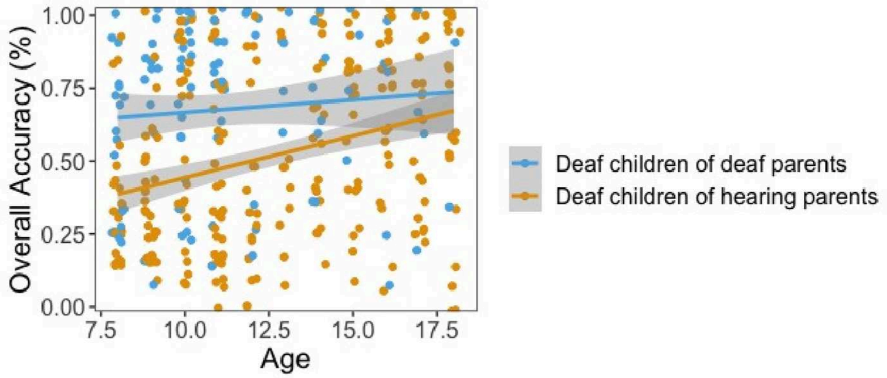

FIGURE 4 | The proportion of the questions answered correctly as a function of age and parental hearing status. Points were jittered slightly to avoid overlap.

(continuous), and type of question (literal, inferential). Random effects were included for story, participants, and items. Analysis revealed significant effects of participant group and question type: deaf children with deaf parents had higher accuracy than deaf children with hearing parents ($M_{\text{deafparents}} = 0.68$, $sd = 0.28$; $M_{\text{hearingparents}} = 0.52$, $sd = 0.30$), and literal questions were answered more accurately than inferential questions ($M_{\text{literal}} = 0.58$, $sd = 0.32$; $M_{\text{inferential}} = 0.55$, $sd = 0.33$). Age was also a positive and significant predictor of performance.[3] Children who have deaf parents appear to reach ceiling at about 12-years-old, which aligns with the target age range for this instrument (see **Figure 3**).

To investigate possible interaction effects, we ran a second regression model (Model 2) in which we added an interaction between parent hearing status and age, and an interaction between parent hearing status and question type. This analysis revealed no significant interaction effects. Further, Akaike's information criterion (AIC) revealed that adding the interaction terms to the model did not improve model fit: Model 2 (AIC = 4875.4) did not improve the model fit as compared to Model 1 [AIC = 4874.5; $\chi_2 = 3.07$, $p = 0.22$]. There were no significant differences in the developmental trajectories of ASL text comprehension in deaf children with deaf vs. hearing parents, and no interaction between question type and participant group.

For many deaf children, age of entry to school marks the time they are first immersed in ASL as a language of communication and instruction. For the subset of participants for whom we had information about age of entry to school ($n = 202$), we investigated the relationship between age of entry and performance on ASL-CMP by parental hearing status. We performed a mixed-effects logistic regression that was the same as the base model described above but also included an interaction between the participant group and age of school entry. We found a significant interaction between age of entry and parent hearing status ($\beta = 0.18$, $SE = 0.09$, $z = -1.98$, $p = 0.047$). *Post-hoc* analyses indicated that, as predicted, there was a significant, positive correlation between age of entry and performance for the deaf children of hearing parents ($n = 154$; $\beta = -0.10$, $SE = 0.03$, $z = 3.17$, $p = 0.002$), but not for the deaf children of deaf parents ($n = 48$; $\beta = 0.08$, $SE = 0.09$, $z = -0.93$, $p = 0.35$). This suggests that children who may have limited exposure to ASL at home show an increase in performance as a function of the amount of time they have spent in a school where ASL is the primary language of instruction.

[3]A spearman correlation between age and ASL-CMP score was also significant ($r_s = 0.19$, $p < 0.01$).

DISCUSSION

In this study, we presented the development and validation of the ASL-CMP, a new ASL text comprehension task. We piloted the task on a group of native deaf signing adults, and then conducted a validation study with over 100 deaf children with deaf parents. This led to subsequent adjustments to ensure the task had high internal consistency and concurrent validity. We then analyzed performance in a group of more than 300 deaf children. Our findings suggest that the ASL-CMP is sensitive enough to detect patterns that are expected based on existing reports of deaf children's academic development, and is an appropriate measure of ASL text comprehension skills in children younger than 12 years of age. Below we discuss the primary findings, along with limitations and areas for further research.

As expected, deaf children of deaf parents, who were more likely to be exposed to ASL from birth, outperformed deaf children with hearing parents, who had more variable ages of exposure to ASL (Kuntze et al., 2014; Mitchiner, 2014; Henner et al., 2016; Hrastinski and Wilbur, 2016; Hall, 2017). Children with deaf parents are likely to be exposed to ASL from a wider range of individuals and in a broad range of contexts. This may lead to increased opportunities to develop inference-making skills, in which they need to extract information from ASL that is not explicitly stated. In contrast, deaf children with hearing parents may have had fewer opportunities to use ASL in these ways. Despite later exposure to ASL among the deaf children who have hearing parents, as a group they still showed evidence of development of higher-level comprehension skills in ASL

TABLE 2 | Mixed effects logistic regression of factors predicting accuracy on the ASL-CMP.

Predictors	**Model 1**			**Model 2**		
	Odds ratios	**CI**	***p***	**Odds ratios**	**CI**	***p***
(Intercept)	0.58	0.26–1.28	0.179	1.26	0.31–5.06	0.742
Age	1.15	1.09–1.22	**<0.001**	1.07	0.95–1.20	0.275
Type of Question (Literal)	1.23	1.06–1.42	**0.006**	1.39	1.05–1.84	**0.021**
Parent hearing status (hearing)	0.33	0.22–0.48	**<0.001**	0.12	0.02–0.57	**0.008**
Age * Parent hearing status (hearing)				1.10	0.97–1.26	0.145
Parent hearing status (hearing) * Types of Question (Literal)				0.84	0.61–1.17	0.309
Random effects						
σ^2	3.29	3.29				
τ_{00}	$2.21_{StudentID}$	$2.19_{StudentID}$				
	0.09_{Story}	0.09_{Story}				
ICC	0.41	0.41				
N	3_{Story}	3_{Story}				
	$356_{StudentID}$	$356_{StudentID}$				
Observations	4,296	4,296				
Marginal R^2/Conditional R^2	0.063/0.448	0.065/0.448				
AIC	4874.5	4875.4				

Model one demonstrates original factors, while model two also includes two interaction terms.

over time. Further, it is important to note that not all deaf children with hearing parents performed below those with deaf parents. We speculate that many hearing parents who learn ASL likely provide a similarly rich environment for learning ASL as that provided by many deaf parents. This is additionally revealed in our analysis of age of school entry, which was a significant predictor of performance on the ASL-CMP for children with hearing parents. This provides promising evidence that exposure to ASL, even if it begins at school entry, can support students' acquisition of higher level ASL comprehension skills.

Our data revealed developmental patterns in deaf children's ASL text comprehension. Specifically, we found that older children had higher scores on the ASL-CMP than younger children. This pattern was particularly evident for children of deaf parents between the ages of 8 and 12 years and for children with hearing parents. This parallels findings from studies of literacy development in written language which show that text comprehension develops over a similar age range (Pettit and Cockriel, 1974; Cain et al., 2001; Silva and Cain, 2015). Many of the older children, particularly those with deaf parents, appeared to have already developed the ability to comprehend the ASL texts used in the task by 8-years-old. In future studies, it will be important to include deaf children who have deaf parents younger than 8 years, to better understand when comprehension skills are first developed among deaf children with early language exposure.

Lastly, there was a small but significant difference in accuracy on the ASL-CMP task based on the type of question, with higher overall accuracy on literal questions than on inferential questions. This is also compatible with previous studies showing literal comprehension is acquired prior to inferential comprehension (Pettit and Cockriel, 1974; McCormick, 1992; Basaraba et al., 2013). This suggests that literal comprehension may serve as a precursor to the ability to make inferences about information that is not explicitly stated in the text. Importantly, our findings are based on a small number of items, and the magnitude of the difference in performance between literal and inferential questions was small. We speculate that these differences would hold across a larger sample, but this must be borne out in future research.

Educational Application of the ASL-CMP

The ASL-CMP is a tool for measuring ASL text comprehension in deaf children ages 8 to 12, and will be useful for a range of purposes. First, the ASL-CMP provides a broad-strokes understanding of how ASL text comprehension develops over childhood. Since this task has been normed using a relatively large group of deaf children of deaf parents, it can be useful for clinicians and practitioners in determining whether a child has age-appropriate ASL text comprehension skills. Teachers may use this task to adapt their instruction to support the development of higher-level thinking skills, and to assess the quality and effectiveness of their ASL instructional approaches. Importantly, although the task has been normed, the ASL-CMP is not intended to diagnose deaf children with language delays. Instead, we recommend that this assessment be used to complement existing ASL assessments in that it measures more advanced language skills than are currently possible.

The ASL-CMP is a computer-based test that is automatically scored. No expertise or training is needed to administer the task. Scores at the individual and school level can be delivered rapidly. This is especially important for deaf children who attend classrooms in which there are no professionals who are fluent in ASL (Hoffmeister, 1988; Hrastinski and Wilbur, 2016; Henner et al., 2018). Inquiries about using the ASL Text Comprehension can be directed to The Learning Center for the Deaf Center for Research and Training at CRT@tlcdeaf.org or to their website (www.ASLEducation.org).

Theoretical Implications of the ASL-CMP

While text comprehension was previously conceived of primarily as the comprehension of a written composition (e.g., a book, article, essay, poem), a broader conception of literacy makes it possible to see that higher-level thinking skills underlie the ability to consume compositions of a wide range of forms. Because these different forms of literacy may share a common underlying proficiency (Mackey and Jacobson, 2014), developing literacy skills through engagement with one type of text may generalize and benefit children's ability to comprehend additional text types (Mayer and Sims, 1994; Mayer, 2009), both within and across languages. It is important to consider how ASL text comprehension might then support children's development of other skills, both in ASL and other languages such as English. Specifically, one might expect those with strong ASL text comprehension skills to also develop strong English literacy skills (Bailes, 2001; Cummins, 2006; Kuntze et al., 2014; Hrastinski and Wilbur, 2016). With this novel way of assessing ASL text comprehension, we can begin to empirically test these questions.

Limitations and Areas for Further Research

The data here show a clear ceiling at around 12 years of age, but children as young as eight already achieve above-chance performance, so more data is needed to determine if the test is appropriate for children younger than eight. The sample size, although larger than many studies of deaf children, is relatively small compared to most normative samples. In a larger sample we may expect to see more robust interactions between participant group and age, as well as more fine-grained development of literal and inferential comprehension skills. Another limitation is that, because we did not have full demographic information on all of the participants in our sample, we were not able to tease out individual differences and how they impacted performance on the ASL-CMP. Due to the small number of questions, seven literal and five inferential, the ASL-CMP cannot reliably distinguish literal and inferential comprehension as two independent constructs, but rather it provides a measure of overall ASL comprehension. Finally, in the current analysis we looked at correct responses only. In future work we hope to carry out an analysis of incorrect responses to determine whether children are more likely to choose distractors of a specific type.

CONCLUSION

In summary, development of text comprehension skills in ASL is an important component of language and literacy development among deaf children. The newly developed ASL-CMP task is a first step in understanding how high-level text comprehension skills develop in children learning ASL. Our task is sensitive to ASL text comprehension in children from a wide range of backgrounds, and suggests that ASL text comprehension improves as children are exposed to ASL both at home and at school. The ASL-CMP makes it possible to evaluate children's ASL text comprehension skills, and identify children who may need support in developing such skills. Further, with a direct assessment of deaf children's text comprehension skills in ASL, we can begin to identify strategies to improve text comprehension skills in deaf children across languages.

DATA AVAILABILITY STATEMENT

The dataset is available on OSF along with the transcripts of the ASL texts in the ASL-CMP (https://osf.io/dwhba/?view_only=None).

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by IRB approval was provided by the Boston University Charles River Campus Institutional Review Board. Consent for data collection was provided via Blanket Consent procedures. Parents were required to opt their children out of assessment. Information about the assessment was provided in both print and via ASL videos. Adults over the age of 18 who were included in assessment were also provided text or video consent documents. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

PR contributed to the study design, carried out data collection, analysis, and manuscript preparation. AL and NC contributed to data analysis and manuscript preparation. Lastly, RH encouraged PR to design the ASL-CMP and supervised the study design and data collection. All authors discussed the results and contributed to the final manuscript.

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