Real-time lexical comprehension in young children learning American Sign Language (ASL)

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Author Note:

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Abstract

The ability to interpret language rapidly is critical for the development of language proficiency. Research on real-time sentence processing has used eye movements to measure children's emerging comprehension abilities. Here we developed the first measures of real-time comprehension of a *visual language*, American Sign Language (ASL), by very young children. Participants were 29 native ASL-learning children (16-53 mos, 16 deaf and 13 hearing) and 16 fluent adult signers. Children's real-time processing skills in ASL improved with age, and variation in children's processing efficiency was associated with vocabulary size, linking the ability to establish reference in real time with language learning. Moreover, both deaf and hearing ASL learners showed qualitatively similar patterns of looking behavior, suggesting that visual language processing is shaped by the immediate modality-specific constraints of processing a visual language. These findings indicate that processing efficiency is a fundamental skill essential for language learning regardless of language modality.

Keywords: sign language, language processing, language acquisition

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Finding meaning in a spoken or a signed language requires learning to establish reference during real-time interaction – relying on audition to interpret spoken words, and on vision to interpret manual signs. Starting in infancy, children learning a spoken language make dramatic gains in their ability to link acoustic signals representing lexical forms to objects in the world. Studies of spoken language comprehension have measured children's gaze as they look at pairs of familiar objects while listening to speech naming one of the objects (Fernald, Pinto, Swingley, Weinberg, & McRoberts, 1998; Law & Edwards, 2014; Venker, Eernisse, Saffran, & Ellis Weismer, 2013). Such research finds that young listeners show age-related increases in the speed and accuracy with which they recognize familiar objects, shifting gaze as soon as the auditory information is sufficient to enable referent identification. Moreover, individual differences in real-time processing efficiency predict vocabulary growth and later language and cognitive outcomes (Fernald, Perfors & Marchman, 2006; Marchman & Fernald, 2008).

However, little is known about how children learning a visual language develop skill in comprehending signs from moment to moment. Here, we adapt the Looking-while-Listening (LWL) procedure (Fernald, Zangl, Portillo, & Marchman, 2008) to develop the first high-resolution measures of speed and accuracy in real-time language processing in American Sign Language (ASL). First, we ask whether children learning ASL show age-related increases in processing efficiency parallel to those previously shown in children learning spoken language. Second, we explore whether variability in processing skill among ASL-learning children is related to their expressive vocabulary development, as in children learning spoken language.

Finally, we compare the accuracy and time course of ASL processing in deaf and hearing native-ASL learners.

ASL processing in adults

Psycholinguistic studies with adults show that language processing in signed and spoken languages is similar in many ways. For example, as in spoken language processing, signers are influenced by both lexicality and frequency; non-signs are identified more slowly than real signs (Corina & Emmorey, 1993) and high frequency signs are recognized faster than low frequency signs (Carreiras, Gutiérrez-Sigut, Baquero, & Corina, 2008). Using an eye-tracking procedure, Lieberman, Borovsky, Hatrak, & Mayberry (2014) found that adult signers are also sensitive to sub-lexical features of signs during real-time comprehension, showing evidence of incremental semantic processing.

However, differences between spoken and signed languages in the linguistic structure and surface features of lexical forms could have consequences for the time course of sign interpretation (Corina & Knapp, 2006). Using a gating procedure, Emmorey & Corina (1990) showed deaf adults increasingly longer videos of signs in isolation and asked them to identify the signs in an open-ended, non-timed response format. English speakers in this study heard increasingly longer segments of spoken words in isolation. Accurate identification of signed words required relatively less of the linguistic signal as compared to spoken word identification, suggesting that features of visual-manual languages such as simultaneous presentation of phonological information might alter the time course of lexical access. Thus, there are parallels and differences between signed and spoken language processing by adults. However, no previous studies have explored the development of real-time language comprehension in young ASL-learners.

Lexical development in ASL

Diary studies of sign language acquisition show that ASL-learners follow a similar developmental path as children learning spoken languages (Lillo-Martin, 1999; Mayberry & Squires, 2006). For example, young signers typically produce recognizable signs before the end of the first year and two-sign sentences by their 2nd birthday (Newport & Meier, 1985). And as in spoken language, young ASL learners tend first to learn more nouns than verbs or other predicates (Anderson & Reilly, 2002).

Other research has investigated how the visual nature of sign language might influence children's interactions with caregivers and thus affect learning mechanisms such as joint attention that support lexical development (Tomasello & Farrar, 1986). Because children learning ASL must rely on vision both to process linguistic information and to look at referenced objects, they must alternate gaze between the signer and objects in the environment to achieve joint attention (Harris & Mohay, 1997). In an observational study of caregiver-child interactions in deaf and hearing dyads, Lieberman, Hatrak, and Mayberry (2014) found that deaf children frequently shifted their gaze to caregivers during book reading to maintain contact with the signed signal. Hearing children, in contrast, looked continuously at the book while the caregiver was speaking, rarely shifting gaze to the caregiver.

Taken together, these findings show that lexical development in children learning signed and spoken languages is parallel in important ways, but that modality-specific features could alter the time-course of establishing reference for children learning a visual language. Yet little is known about potential differences between deaf and hearing ASL learners in their real-time comprehension of ASL. One possibility is that the time course of lexical access will be similar in deaf and hearing signers, driven by the immediate modality-specific constraints of comprehending a visual language in real time. Another possibility is that given their extensive experience relying on vision to monitor both the linguistic signal and the named referent, deaf children will wait longer to disengage from the signer than hearing children. Here, we present the first comparison of real-time processing in deaf and hearing native-ASL learners.

Research questions

By adapting the LWL procedure (Fernald et al., 2008), a well-established paradigm for measuring spoken language processing efficiency in young visual language learners, we addressed three main questions. First, do children learning ASL show development of speed and accuracy in real-time processing of familiar signs in ways that are parallel to children learning spoken language? Second, are differences among ASL-learning children in real-time processing skills related to differences in expressive vocabulary development, as in children learning spoken language? And third, how do deaf and hearing ASL-learners compare in the accuracy and time course of real-time lexical processing?

Method

Participants

Participants were 16 deaf and 13 hearing children with native exposure to ASL (17 females, 12 males, M_{Age}= 28.5 months, range = 16-53 months) and 16 fluent adult signers. Children learning ASL from birth from a native signer are a difficult population to recruit, given that approximately 95% of deaf children are born to hearing parents with little or no prior exposure to a signed language (Mitchell & Karchmer, 2004). The majority of child participants were recruited through a center-based child education program in which ASL was the mode of instruction. All children, regardless of hearing status, were exposed to ASL from birth through extensive interaction with at least one fluent ASL caregiver, and they currently used ASL as their primary mode of communication at home. Adult participants were all fluent signers who reported using ASL as their primary method of communication. Our sample size was determined by our success over the 2-year period of an NIDCD R21 grant in recruiting and testing children and adults who were native ASL users. An additional 17 child participants were tested but not included in the analyses because they were not exposed to ASL from birth (n = 12), or they did not complete the real-time language assessment (n = 5).

Measures

Expressive vocabulary size: Parents completed a 90-item vocabulary checklist based on the MacArthur-Bates Communicative Development Inventories (Fenson et al., 2007) adapted for children learning ASL. Vocabulary size was computed as the number of signs reported to be produced.

ASL Processing: Efficiency in online comprehension was assessed using a version of the LWL procedure adapted for ASL learners, which we call the Visual Language Processing (VLP) task. The VLP task yields two measures of processing efficiency, reaction time (RT) and accuracy. Since this is the first study to develop measures of online ASL processing efficiency in children of this age, several important modifications to the procedure were made, as described below.

Procedure

The VLP task was presented on a Macbook Pro laptop connected to a 27” monitor. The child sat on their caregiver’s lap, and the child’s gaze was recorded using a digital camcorder set up behind the monitor. To minimize visual distractions, testing occurred in a portable 5’ by 5’ tent, which reduced visual distractions during the task. On each trial, pictures of two familiar objects appeared on the screen, a target object corresponding to the target noun, and a distracter object matched for visual salience. Between these two pictures was a central video of an adult female signing the name of one of the pictures. Participants saw 32 test trials with five filler trials (e.g. "YOU LIKE PICTURES? MORE WANT?") interspersed to maintain children's interest.

Coding and Reliability. Participants' gaze patterns were videotaped and later coded frame-by-frame at 33-ms resolution by highly-trained coders blind to target side. On each trial, coders indicated whether the eyes were fixated on the central signer, one of the images, shifting between pictures, or away (off), yielding a high-resolution record of eye movements aligned with target noun onset. Prior to coding, all trials for child participants were pre-screened to exclude those few with parental interference on a trial-by-trial basis. To assess inter-coder reliability, 25% of the videos were re-coded. Agreement within a single frame averaged 98% on these reliability assessments.

Stimuli

Linguistic stimuli. To allow for generalization beyond characteristics of a specific signer and sentence structure, we recorded two separate sets of ASL stimuli. Both sets were recorded with a native ASL user, and each set used a different but acceptable ASL sentence structure for asking questions (see Petronio and Lillo-Martin, 1997):

- Sentence-initial wh-phrase: "HEY! WHERE [target noun]?"
- Sentence-final wh-phrase: "HEY! [target noun] WHERE?"

To prepare the stimuli, two female native ASL users recorded several tokens of each sentence in a child-directed register. Before each sentence, the signer made a hand-wave gesture commonly used in ASL to gain an interlocutor's attention before initiating an utterance. These candidate stimuli were digitized, analyzed, and edited using Final Cut Pro software. The final tokens were chosen based on naturalness.

Visual stimuli. Target nouns consisted of eight object names familiar to most children learning ASL at this age. Visual stimuli consisted of colorful digitized pictures of these objects presented in four fixed pairs, in which the object names had no phonological overlap (cat—bird, car—book, bear—doll, ball—shoe). Images were digitized pictures presented in fixed pairs, matched for visual salience with 3–4 tokens of each object type. Each object served as target four times and as distracter four times. Side of target picture was counterbalanced across trials.

Trial Structure

Figure 1 shows the structure of a trial with one question type (sentence final wh-phrase) in the VLP task. On each trial, the child saw two images of familiar objects on the screen for 2 s before the signer appeared, allowing the child to inspect both images. Next, children saw a still frame of the signer for 1 s, so they could orient to the signer prior to sentence onset. The target sentence was then presented, followed by a question and 2-s hold, followed by an exclamation to encourage attention to the task.

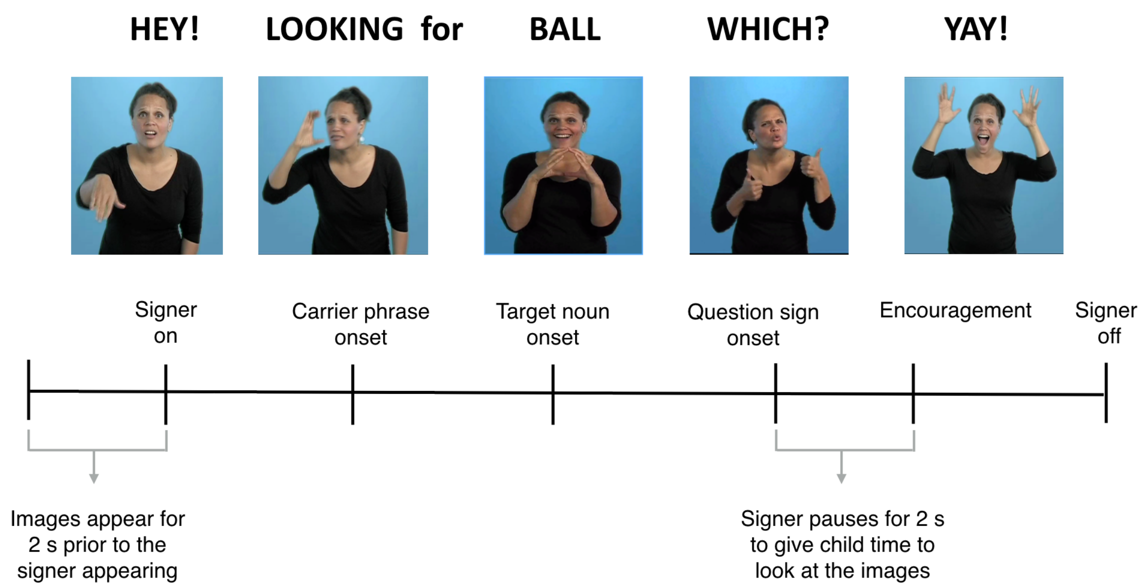

Figure 1: *Overview of the trial structure for one question type (sentence final wh-phrase) shown in the central video on the VLP task.*

Calculating measures of linguistic processing efficiency

Computing target sign onset. In studies of spoken language processing, target word onset is typically identified as the first moment in the auditory signal when there is acoustic evidence of the target word. However, in signed languages like ASL, phonological information is presented in several parts of the visual signal simultaneously – for example, in both the hands and face of the signer - making it difficult to precisely determine the beginning of the target sign. Here, we took an empirical approach to defining target sign onset. We asked 10 fluent adult signers unfamiliar with the stimuli to watch videos of the target signs while viewing the same picture pairs as in the VLP task. For each sign token, final target noun onsets were identified as the earliest point in the signed sentence at which adults discriminated the pictures with 100% agreement.

Reaction Time (RT). Reaction time (RT) corresponds to the latency to shift from the central signer to the target picture on all signer-to-target shifts, measured from onset of the target sign. We chose cutoff response times based on the distribution of children's RTs in our task, selecting the middle 90% (600-2500 ms) (e.g., Ratcliff, 1993). Incorrect shifts (signer-to-distracter (19%), signer-to-away (14%), no shift (8%)) were not included in the computation of median RT.

Target Accuracy. Accuracy was the mean proportion of time spent looking at the target picture out of the total time looking at either target or distracter picture over the 600 to 2500 ms window from target noun onset. Accuracy is determined by the child's tendency to shift quickly from the signer to the target picture in response to the target sign and how well the child maintains fixation on the target picture. Mean proportion looking to target was calculated for each participant for both correct and incorrect shifts.

Results

Our analyses use Bayesian linear models to test our hypotheses of interest and to estimate the associations between age, vocabulary, and RT and accuracy in the VLP task. We analyze our data using Bayesian methods for three reasons. First, since native ASL learners are difficult to recruit, it is critical to exclude as few participants as possible. By using a Bayesian model, we can analyze outlier behavior in a principled way, without appealing to ad hoc criteria. Second, Bayesian methods allow us to quantify support in favor of a null hypothesis of interest –that is, the lack of a difference between deaf and hearing ASL learners' real-time processing skills. And third, relevant prior knowledge can be included to more accurately estimate the strength of the associations between RT/accuracy on the VLP task and age/vocabulary.

Specifically, we used prior work on the development of real-time processing efficiency in children learning spoken language (Fernald et al., 2008) to consider only plausible values of the association strength, thus making our alternative hypotheses more precise. In addition, the common use of RT as a processing measure is based on the assumption that the timing of a child's first shift reflects the speed of their lexical access. Yet, some children have a first shift that seems to be unassociated with lexical access: their first shift behavior appears random. We quantify this possibility for each participant explicitly (i.e., the probability that the participant is a "guesser") and we create an analysis model where participants who were more likely to be guessers have less of an influence on the estimated relations between RT and age/vocabulary. Note that we use this approach only in the analysis of RT, since "guessing behavior" is integral to our measure of children's mean accuracy in the VLP task, but not to our measure of mean RT.

To test if there is developmental change, we report the strength of evidence for a linear model with an intercept and slope compared to an intercept-only model in the form the Bayes Factor (BF) computed via the Savage-Dickey method (Wagenmakers et al., 2010). To estimate the strength of the association, we report the mean of the posterior distribution of the intercept and the slope, and the 95% Highest Density Interval (HDI) of the intercept and slope, which provides information about the uncertainty of our estimate of the linear association. Models with categorical predictors were implemented in STAN (Stan Development Team, 2016), and models with continuous predictors were implemented in JAGS (Plummer, 2003). The Supplemental Material available online presents more detail about model specifications and simulations.

Overview of ASL processing

First we compare real-time processing skills by younger and older ASL-learning children and fluent adult signers. Figure 2 shows changes in the mean proportion of trials on which participants in each age group fixated the signer, the target image, or the distracter image at every 33 ms interval of the stimulus sentence. At the onset of the target sign, all participants were looking at the signer. As the sign unfolded, mean proportion looking to the signer decreased rapidly as participants shifted their gaze to the target or the distracter image. Proportion looking to the target increased sooner and reached a higher asymptote compared to proportion looking to the distracter for all age groups. After looking to the target image, participants tended to rapidly shift their gaze back to the signer, reflected by the increase in proportion looking to signer around 2000 ms after target noun onset. Figure 2 also shows age-related change in real-time ASL processing efficiency. Older children were more accurate than younger children, but not as accurate as adults. Moreover, older children tended to shift to the target picture sooner in the sentence than did younger children, but not as rapidly as adults.

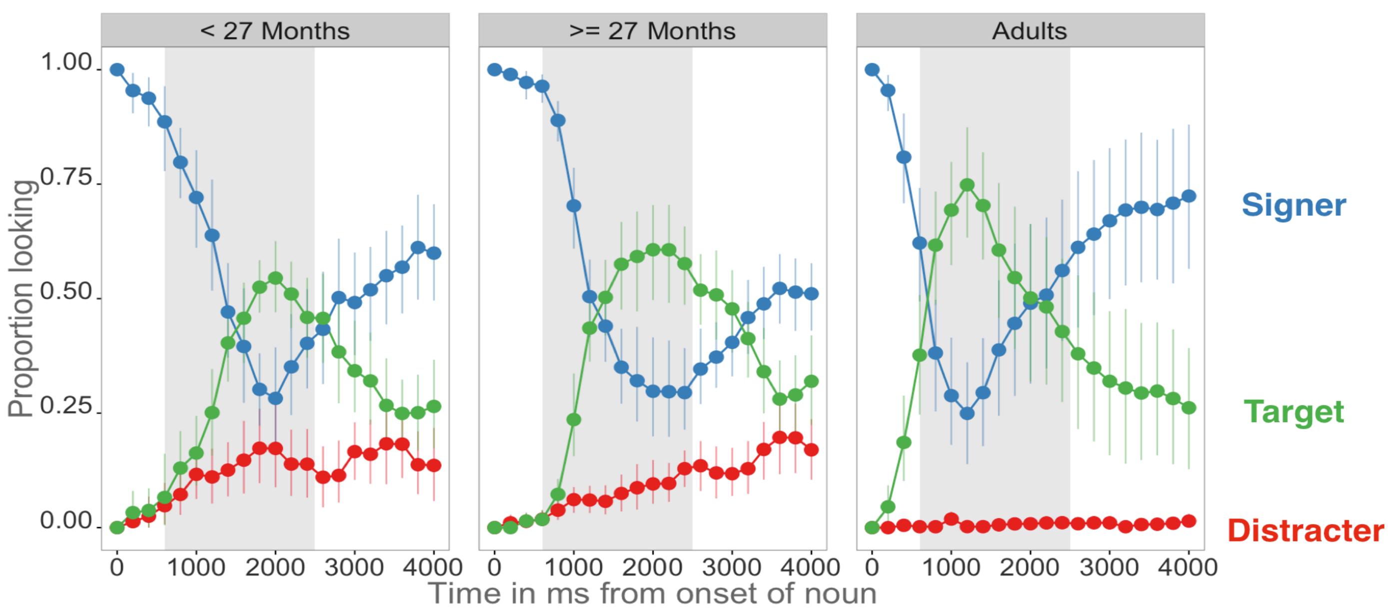

Figure 2: *An overview of the time course of looking behavior for younger children, older children, and adults. The curves show the raw proportion looking to the signer (blue), the target image (green), and the distracter image (red). The grey shaded region represents the analysis window (600-2500ms) and the error bars represent +/- 95% CI computed by non-parametric bootstrap.*

Figure 3 shows group-level summary measures of ASL processing efficiency. When modeling differences between proportions looking to target vs. the distracter pictures, all three groups spent more time looking at the target than the distracter (younger: β_{diff}= 0.35, 95% HDI [0.27, 0.43]; older: β_{diff}= 0.55, 95% HDI [0.47, 0.63]; adults: β_{diff}= 0.81, 95% HDI [0.74, 0.90]). Moreover, even the youngest children were looking at the target more than would be expected by chance (younger: β= 0.59, 95% HDI [0.52, 0.65]; older: β= 0.70, 95% HDI [0.64, 0.76]; adults: β= 0.82, 95% HDI [0.76, 0.88]). In all three groups, proportion looking to distracter was small, decreasing to almost zero in the adults (younger = 0.26, older = 0.15, adults = 0.01). Older children were more accurate than younger children (β_{diff} = 0.09, 95% HDI [0.01, 0.19]) and had shorter mean RT to orient to the target image (β_{diff} = -184.50 ms, 95% HDI [-326.01, -38.48]). Children were less accurate overall (β_{diff} = -0.16, 95% HDI [-0.24, -0.09]) and slower to shift to the target image (β_{diff} = 373.12, 95% HDI [236.64, 503.57]) compared to adults.

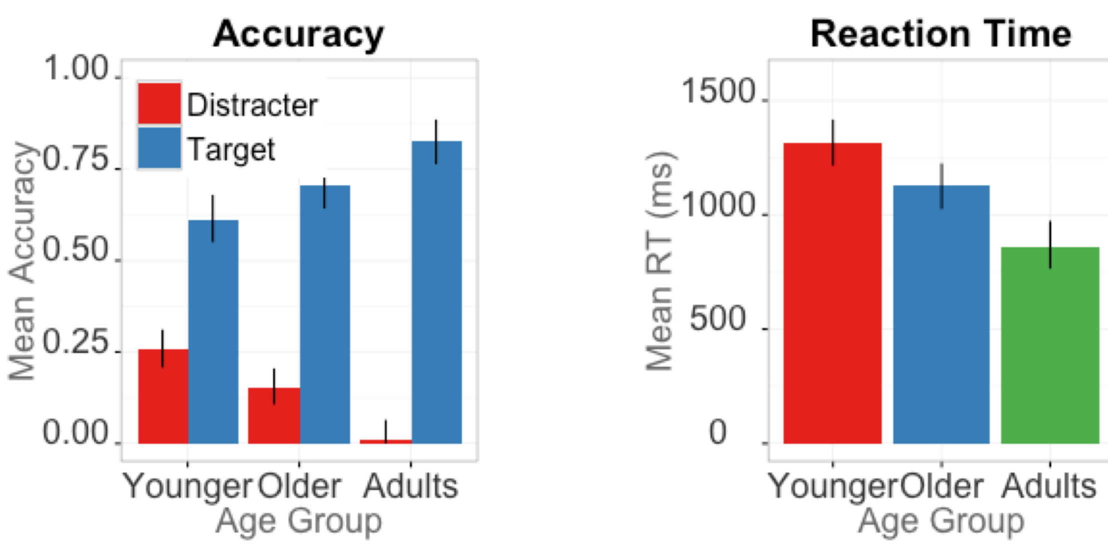

Figure 3. *Summary measures of developmental changes in ASL processing efficiency. The left panel shows mean Accuracy for younger kids, older kids, and adults; the right panel shows mean RT for all three groups. Error bars represent +/- 95% Highest Density Intervals.*

Model	BF_{01}	Mean β	2.5% HDI	97.5% HDI
Accuracy ~ Age	12.8	0.007	0.002	0.012
Accuracy ~ Vocab	6.8	0.003	0.001	0.005
RT ~ Age	12.5	-10.6	-17.98	-3.36
RT ~ Vocab	18.2	-6.27	-10.39	-2.29

Table 1: *Summary of the four linear models using age and vocabulary size to predict accuracy and reaction time. BF_{01} is the Bayes Factor comparing the evidence in favor of linear model to an intercept-only (null) model; Mean β is the mean of the posterior distribution for the slope parameter for each model (i.e., the strength of association); and the Highest Density Interval (HDI) shows the interval containing 95% of the plausible slope values given the model and the data.*

Links between children's age and processing efficiency

We next use Bayesian linear regressions to test whether young ASL learners show age-related increases in the speed and accuracy with which they interpret familiar signs (see Table 1). Mean accuracy was positively associated with age (Figure 4A), indicating that older ASL learners were more accurate than younger children in fixating the target picture. The Bayes Factor was ~11, providing strong evidence for a linear association. The β estimate indicates that for each month of age children increased their accuracy score by 0.007, i.e., an increase of ~1% point, meaning that over the course of one year the model estimates a ~12% point gain in accuracy when establishing reference in the VLP task.

Mean RTs were negatively associated with age (Figure 4B), with older children shifting more quickly to the target picture than younger children. The Bayes Factor was ~12, providing strong evidence for a linear association. The model estimates a ~10 ms gain in RT for each month, leading to a ~120 ms gain in speed of lexical access over a year of development.

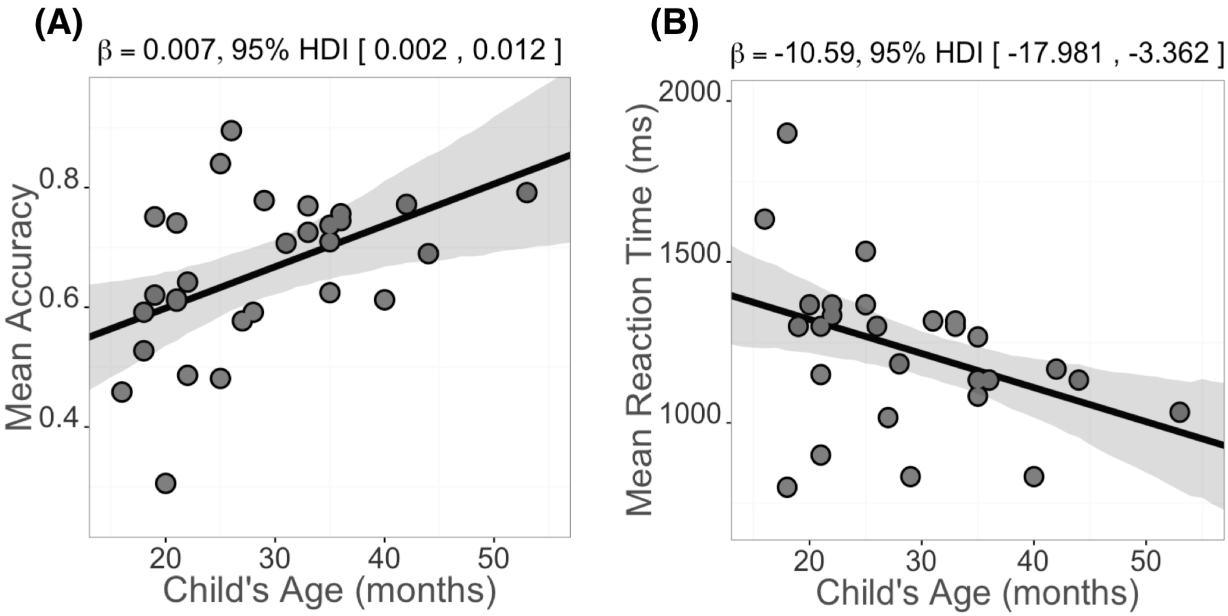

Figure 4: *Scatterplots of the relations between children's age and measures of their mean accuracy (4A) and mean RT (4B) in the VLP procedure. The solid black line is the maximum a posteriori model estimate for the mean accuracy at each age point. The shaded gray regions represent the 95% Highest Density Interval around the regression line.*

Together, the accuracy and RT analyses show that young ASL learners will reliably leave a central signer to shift to a target image in the VLP task. Importantly, children varied in their response times and accuracy, and this variation was meaningfully linked to age. Thus, like children learning spoken language, ASL learners improve their real-time language processing skills over the second and third years of life as they make progress towards adult levels of language fluency.

Links between children's processing efficiency and vocabulary

The next question we addressed was whether individual differences in processing skills were related to the size of children's ASL vocabularies. As shown in Figure 5, children with higher accuracy scores also had larger productive vocabularies (BF_{01} = 6.1), with the model estimating a 0.004 (~0.5%) increase for each additional sign children knew. Moreover, children who were faster to recognize ASL signs were those with larger sign vocabularies (BF_{01} = 18.2), with each additional sign resulting in a ~5 ms decrease in estimated RT.

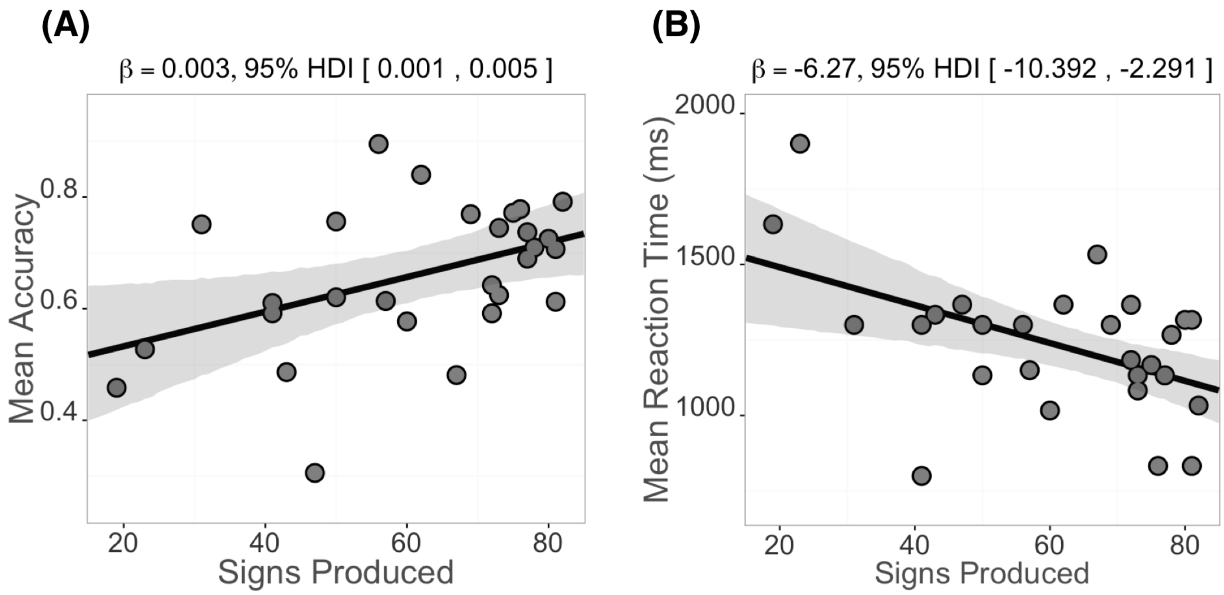

Figure 5*:* *Scatterplot of relations between children's productive ASL vocabulary and measures of their mean accuracy (panel A) and mean RT (panel B) in the VLP procedure. Plotting conventions are the same as in Figure 4.*

Taken together, these analyses indicate that older children and children with larger expressive vocabularies were more accurate and efficient in identifying the referents of familiar signs. These findings parallel results in the substantial body of previous research with monolingual children learning English or Spanish (Fernald et al., 2006; Hurtado, Marchman, & Fernald, 2007).

Effects of hearing status on children's real-time ASL comprehension

Finally, we compared deaf and hearing native ASL-learning children's real-time comprehension of ASL. Would both groups show similar time course of lexical processing, driven by the immediate modality-specific constraints of interpreting a visual language in real time? Or would deaf children's reliance on vision to monitor both the linguistic signal and the referent cause them to wait longer to disengage from the signer?

Figure 6 shows an overview of looking behavior in the VLP task for deaf (n=16, M_{age} = 28m, SD_{age} = 7.48m) and hearing (n=13, M_{age} = 29m, SD_{age} = 11.19m) children. Overall, these two groups showed a similar time course of looking behavior: shifting away from the signer, increasing looks to the target, and shifting back to the signer at similar time points as the sign unfolded. We found no differences in mean accuracy (β_{diff}= -0.04, 95% HDI [-0.13, 0.04]) or RT (β_{diff}= 70.06, 95% HDI [-103.32, 239.64]), with the HDI including zero for both models. Moreover, the Bayes Factor favored the null model indicating no difference between the two groups for each processing measure (BF_{acc} = 2.9, BF_{RT} = 2.9). These analyses provide evidence that hearing and deaf ASL-learners show parallel sensitivity to the modality-specific constraints of processing a visual language in real time.

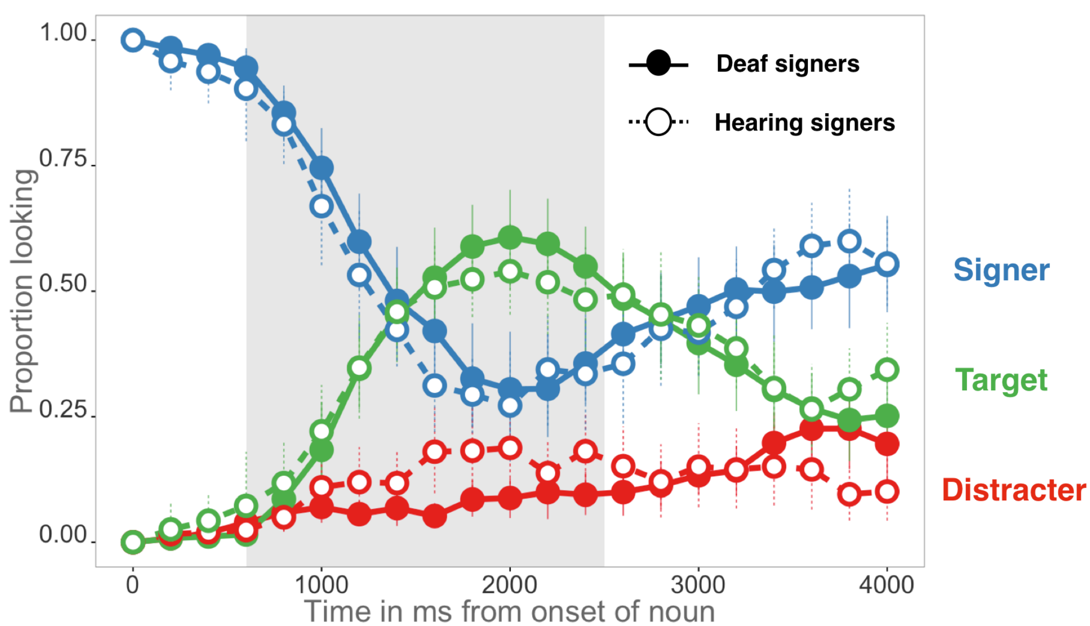

Figure 6. *The time course of looking behavior for young deaf and hearing ASL-learners. The curves show mean proportion looking to the signer (blue), the target image (green), and the distracter image (red). The circle fill and the line type represent hearing status; the grey shaded region represents the analysis window (600-2500ms); error bars represent +/- 95% CI computed by non-parametric bootstrap.*

Discussion

Efficiency in establishing reference in real-time is a fundamental component of language learning. Here, we developed and validated the first measures of young ASL learners' real-time language comprehension skills, exploring how language processing skills are linked to age, vocabulary, and hearing status. There are three main findings from this research.

First, like children learning spoken language (Fernald et al., 1998), young ASL learners showed significant age-related improvements in the efficiency with which they processed language. Even ASL-learning 2-year olds shifted from the signer to the target picture rapidly, with few false alarms to the distracter. However, although all target signs were familiar to both younger and older children, the older children identified the correct referent more quickly and accurately and were less likely to shift to the unlabeled picture. These patterns of developmental change suggest that the real-time comprehension skills of children learning ASL in native contexts follow a similar developmental path to that of children learning spoken language, as has been shown in previous work using other behavioral methods (Lillo-Martin, 1999; Mayberry & Squires, 2006). Prior work on developmental trajectories of deaf children has focused on language production, since production is easier to observe and to measure than comprehension. By developing precise measures of real-time ASL comprehension, we were able to study the emergence of children's language skills much earlier in development than is possible using other methods.

Second, we discovered a link between early ASL processing skills and children's productive ASL vocabularies. ASL-learning children who knew more signs were also faster and more accurate to identify the correct referent than those who were lexically less advanced. These results are consistent with studies with English- and Spanish-learning children, which find strong relations between efficiency in online language comprehension and concurrent and longitudinal measures of linguistic achievement (Fernald et al., 2006; Marchman & Fernald, 2008).

Third, we found that deaf and hearing children learning ASL as a first language were similar in processing speed and accuracy in interpreting signs in real time. Even though the hearing children could use both vision and hearing to process incoming information, this experience did not appear to change the time course of visual language processing compared to their deaf peers. Instead, both groups showed parallel sensitivity to the modality-specific constraints of processing a visual language in real time.

Limitations

This research has several limitations. First, while the sample size was large relative to those in previous research on ASL development, it was still a small sample. To facilitate replication, we have made all of our stimuli, data, and analysis code publicly available (http://kemacdonald.github.io/SOL), with the hope that other researchers will benefit from what we have learned in this work.

Second, testing groups of children within a narrower age range might have revealed independent effects of vocabulary size on both ASL processing measures, which could not be assessed here given the confound between age and vocabulary size in our sample of 1- to 4-year-olds. Thus, more evidence is needed to characterize more precisely the relations between accuracy, RT, and vocabulary in young ASL-learners.

Third, central characteristics of the VLP task make it difficult to directly compare our findings with previous work on ASL and spoken language processing. For example, in contrast to prior ASL gating studies with adults (e.g., Emmorey & Corina, 1990; Morford & Carlsen, 2011), our stimuli were signed as full sentences in a child-directed register, not as isolated signs, and we used a fine-grained temporal response measure rather than an open-ended untimed response. Moreover, the VLP task included the signer as a central fixation image, resulting in quite different task demands from those in research using the two-alternative LWL procedure to study the development of children's spoken language processing (e.g., Fernald et al. 1998). Given these differences, we cannot make any general claims about the time course of processing in signed vs. spoken languages in absolute terms. However, our results show impressive parallels with previous findings on the early development of efficiency in real-time processing by children learning spoken languages in terms links to measures of vocabulary.

Finally, our sample is not representative of the majority of children learning ASL in the United States. We took great care to include only children who were native signers with exposure to ASL from birth. It is very likely that the development of real-time language processing would look different in children who are late learners or who have more heterogeneous and inconsistent exposure to ASL. An important next step is to explore how differences in ASL processing are influenced by differences in children's experience with signed languages. Since children's efficiency of real-time processing of spoken language is linked to the quantity and quality of the speech that they hear (Hurtado, Marchman, & Fernald, 2008; Weisleder & Fernald, 2013), we would expect similar relations in children learning ASL. We hope that the VLP task will provide a useful method for both researchers and educators, providing a way to precisely track developmental trajectories of children learning ASL.

In conclusion, this study provides the first evidence that young ASL learners' processing skills are meaningfully linked to age and to vocabulary outcomes. These results contribute to a growing literature highlighting parallels between signed and spoken language development when children are exposed to native sign input. Moreover, we found similar results for deaf and hearing ASL-learning children, suggesting that both groups were sensitive to the modality-specific constraints of processing a visual language in real-time. These findings indicate that processing efficiency is a fundamental skill essential for language learning regardless of language modality.

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