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Word recognition and learning in signing deaf toddlers

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ABSTRACT

Deaf children acquiring American Sign Language (ASL) perceive both linguistic and non-linguistic information through the visual mode. Thus, signing deaf children face a unique task in word learning, in that mapping objects to referents requires careful allocation of visual attention. This study investigates how perceptual experience and language modality influence both the moment-by-moment and developmental timecourse of word recognition and word learning. We analyzed data from two eyetracking experiments, previously reported in Lieberman, Fitch, and Borovsky (2022). Deaf children ($N = 52$, 18–71 months old, $M_{age} = 47$ months) were first exposed to familiar and novel words, and then tested on the speed and accuracy of word recognition. Here we focus on the previously-unanalyzed familiar word trials. We ask what factors predict familiar word recognition, and whether familiar word recognition is related to novel word learning in ASL. We found that children's accuracy on familiar word recognition improves across developmental time. We did not find evidence for differences in looking behavior based on parent hearing status or recent exposure to the word. Individual differences in children's performance on familiar word trials correlated with their accuracy in novel sign recognition. Despite the increased attentional demands of word learning in a visual language, we find parallels between signed and spoken languages in children's developing word recognition accuracy and in the relationship between word recognition and word learning.

1. Introduction

Over the first few years of life, infants learn to recognize thousands of words, and this sets the stage for children to acquire a rich vocabulary. Indeed, in spoken language, children who recognize familiar words more quickly also tend to learn new words more successfully and grow their vocabularies faster (Lany, 2018; McMurray et al., 2012; Ronfard et al., 2022). The relationship between lexical processing and word learning in sign languages such as American Sign Language (ASL) has not been systematically explored. The demands of mapping words to their referents in the visual modality may lead to unique relationships between familiar word processing and novel word learning. Here, we investigate this processing–learning link in ASL, examining age-related patterns in word recognition and their relation to novel sign acquisition.

1.1. Early word recognition across modalities

Even before infants produce their first words, they recognize and comprehend words for common objects and people in their environment. This early comprehension has been demonstrated in infants as young as 6 months (Bergelson & Swingley, 2012; Tincoff & Jusczyk, 1999). Studies in spoken language have consistently demonstrated that infants and toddlers show increasing efficiency in recognizing familiar words as they grow older (Cao et al., 2025; Fernald et al., 1998; Frank et al., 2025). For example, between infants' first and second birthdays, they become faster and more accurate at looking to a named target image (Bergelson, 2020; Fernald et al., 1998). By 24 months, infants can use partial information, i.e. the initial sound or syllable of a word, to correctly identify the word (Fernald et al., 1998; Fernald et al., 2001). A recent large-scale analysis of data across two dozen eyetracking studies reported that between one and six years old, word recognition becomes faster, more accurate, and less variable (Frank et al., 2025).

Word recognition efficiency continues to improve throughout childhood and even into adolescence (Frank et al., 2025; Rigler et al., 2015). Rapid familiar word recognition is a prerequisite for utterance-level or discourse-level language processing (Marchman & Fernald, 2008). To date, however, most of our knowledge about early word

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recognition has come from studies of spoken languages (though c.f., MacDonald et al., 2018). Much less is known about lexical recognition of signs. This limits our understanding of how modality-specific features influence the development of word learning.

On the one hand, we might not expect sign language word recognition to differ from spoken language; sign language acquisition largely parallels spoken language acquisition (Mann et al., 2016; Mayberry & Squires, 2006; Mercure et al., 2025; Petitto, 1999; Sandler & Lillo-Martin, 2006). Deaf children who receive exposure to a sign language from birth babble with their hands (Petitto & Marentette, 1991), produce first words around the same time (if not earlier) as spoken language learners (Meier & Newport, 1990), and approach word learning using parallel constraints as spoken language learners, including applying a mutual exclusivity constraint (Fitch & Lieberman, 2025) and fast-mapping a novel sign to a novel object (Lieberman et al., 2022) In deaf adults with sign language exposure from birth, behavioral and neural measures of sign lexical processing largely resemble spoken language lexical processing (e.g., Carreiras et al., 2008; MacSweeney et al., 2008). Like spoken language, sign language recognition is faster in sentential contexts versus in isolation (Clark & Grosjean, 1982; Grant & Seitz, 2000), varies based on language exposure (Lieberman et al., 2015; McDonald & Zamuner, 2025; Morford et al., 2014), and is subject to interference from phonological or semantic competitors (Gutierrez et al., 2012; Lieberman & Borovsky, 2020; Lieberman et al., 2015).

In both spoken and signed languages, one would generally expect familiar word recognition and novel word learning to be positively related. However, the way this relationship manifests may be shaped by how visual attention is coordinated in ASL. Spoken language learners can maintain auditory attention on the linguistic signal while directing visual attention to relevant objects. ASL learners must alternate visual attention between the language signal (i.e., the signer) and the referent in the environment, although some information could also be available through peripheral vision. This process places unique demands on motor coordination, visual attention, and cognitive flexibility. Prior research has shown that deaf children are particularly adept at allocating attention between language and non-linguistic information (Lieberman et al., 2014; Lieberman et al., 2022), a skill that may support efficient word recognition in ASL. Thus, the visual nature of ASL may introduce modality-specific demands that shape word recognition and learning.

Developmental changes in processing efficiency are driven by several interrelated cognitive and linguistic mechanisms that may operate differently in spoken vs signed languages. First, as children's vocabularies expand, their familiarity with words grows, allowing them to more quickly match incoming linguistic input to stored lexical representations. This process is supported by improvements in phonological processing, which enable children to better discriminate between similar-sounding words and recover from misperceptions (Metsala et al., 2009; Mills et al., 2004). While phonemes in spoken language words unfold across time, sign perceivers have instant and immediate access to a large amount of phonological information in a sign. Handshape, palm orientation, location of the hands, and facial expression can all be perceived simultaneously in sign language (excluding more complex constructions such as classifiers and compound signs). Second, maturation of attentional control and processing speed facilitates faster integration of linguistic and contextual cues (Lorsbach & Reimer, 2008; Rohde & Ettlinger, 2012; Yu & Ballard, 2007). In sign language, this allocation of attention all occurs within the visual modality, so children must learn to alternate visual attention in order to perceive both linguistic and referential information. Additionally, deaf children or children with exposure to sign language may become more adept at leveraging information in the periphery; deaf signing adults often outperform hearing adults on tasks involving peripheral vision (Bottari et al., 2010; Brazão et al., 2021; Chen et al., 2010; Codina et al., 2011; Codina et al., 2017; Li et al., 2022; Lore & Song, 1991; Parasnis & Samar, 1985), and by the teenage years, deaf signing children outperform hearing non-signing children on tasks requiring detection of information in the periphery (Codina et al., 2011). Finally, increased experience with language in meaningful social contexts enhances children's predictive processing abilities (Ito & Sakai, 2021), enabling them to anticipate likely referents based on the linguistic signal and the visual scene. While children acquiring ASL also leverage semantic prediction (Lieberman et al., 2018), they may be less likely to leverage syntactic cues given the more flexible word order in ASL as compared to spoken English. In contrast, deaf children appear to leverage the robust presence of iconicity in sign language in their early vocabularies (Perlman et al., 2018; Wescott, 1971), and the iconic mappings are often shared across multiple signs (Campbell et al., 2025), which may lead to unique patterns of lexical processing in sign.

A few studies have investigated real-time lexical processing in children acquiring a sign language. MacDonald et al. (2018) measured sign recognition in a sample of 16 deaf children and 13 hearing children with deaf parents (CODAs) between 16 and 53 months of age. The authors found that children became faster and more accurate in familiar word recognition with age. Further, signing children look away from the signer before the sign ends. On average, children launched a fixation away from the signer after ∼80% of the sign (compared to adults who looked away from the signer after only ∼50% of the sign). MacDonald et al. (2018) also found that children who were faster and more accurate at word recognition tended to have larger vocabulary sizes. These gaze behaviors seem related to signing experience rather than hearing status; deaf children and CODAs had similar accuracy and reaction times in the familiar word recognition task.

In school-age deaf children (4-to-8-years-old), Lieberman & Borovsky (2020) found high accuracy in word recognition (i.e., all participants looked to the named referent ≥70% of the 1500 ms after the target word). Children's word recognition patterns showed influence from semantic and phonological competitors. The authors did not find evidence for differences across the 4-to-8-year age range, suggesting that at least some aspects of familiar word recognition are relatively stable by 4 years of age.

1.2. *Recognition skills predict word learning*

Young children's word processing has been linked to a number of additional language acquisition milestones, and is predictive of later vocabulary. Speed of recognition of familiar words at 25 months correlates with lexical and grammatical development over the second year (Fernald et al., 2006), and is predictive of later linguistic and cognitive skills (Marchman & Fernald, 2008). In Frank et al. (2025)'s meta-analysis, children who showed faster word recognition also showed faster vocabulary growth. Of particular relevance to the current study, several studies have found that individual differences in lexical processing efficiency, measured as the speed at which children recognize a familiar word, correlates with children's ability to learn novel words in a fast-mapping task (Lany, 2018; Ronfard et al., 2022).

Once again, most studies probing word processing and learning draw on spoken language development. Investigating the relationship between processing and learning in sign language sheds light on some of the possible mechanisms underlying this relationship. For example, some explanations suggest that rapid word recognition facilitates learning, in that children who can quickly process incoming linguistic input can then shift their attentional resources to mapping that input onto the surrounding visual scene. However, this relationship is difficult to assess in spoken language because we cannot overtly observe children's attention to auditory linguistic input. In contrast, children perceiving sign language must allocate visual attention to *both* the unfolding linguistic input and to mapping that input to objects and events in their environment. Thus, if processing signs and mapping novel signs to their referents are related among children acquiring sign language, this would provide support for an attentional account of the processing-learning relationship. In fact, the unique demands on attentional control required to map visual linguistic input to visual referents make the investigation of sign language learners particularly pertinent to theories of word processing and learning. Children who are able to quickly process a visual wordform may be able to shift their attention rapidly away from the linguistic signal and towards the visual scene. Children who are slower to process a sign may miss these cues or have less time to encode the referent. Alternatively, there may be advantages to sustaining attention towards the linguistic signal for longer, such that the sign can be fully perceived and encoded before shifting attention to the corresponding visual scene (MacDonald et al., 2020).

2. The present study

In the present study, we characterize how ASL word recognition varies as a function of age. We had two primary goals: The first was to replicate prior findings regarding the development of familiar word recognition in ASL. In line with previous findings (MacDonald et al., 2018), we hypothesize that children will become more efficient as they get older, with older children initiating gaze shifts away from the signer and towards the pictures more quickly than younger children. We also predict that older children will have higher accuracy and will spend a greater amount of time overall looking at the target picture relative to younger children. The second goal was to determine whether children's processing of familiar signs is related to their ability to acquire new words. If ASL shows the same empirical pattern observed in spoken languages, then we would predict a positive correlation between reaction time during familiar word recognition and accuracy in mapping a recently learned novel sign to a novel object. Alternatively, if the coordination of visual attention–-required to shift gaze between signs and objects–-shows protracted development, then we may see a less robust relationship between speed of word recognition and novel word learning.

3. Methods

Data were drawn from two related eyetracking experiments presented in Lieberman et al. (2022). These experiments were designed to study children's fast-mapping with varying exposure conditions to the novel word. For the present analyses, we analyze the previously-unanalyzed "control" trials of these experiments, which were familiar words, to determine predictors of familiar word recognition. In addition, we revisit Lieberman et al. (2022)'s measure of word learning–-looking time to novel words during test trials–- to see how individual differences in familiar word processing efficiency relate to novel word learning in ASL.

3.1. Participants

The protocol was approved by the Institutional Review Board at Boston University. Parents provided informed consent. Participants were recruited from the Northeast, Mid-Atlantic, and Midwestern United States, through social media and through programs serving deaf children. Inclusion criteria were that children were between the ages of 18 months to six years old, deaf or hard of hearing, had normal or corrected-to-normal vision, and were learning ASL as their primary language. All children attended an early intervention program that used ASL. Parent hearing status was not an inclusion criterion; all parents reported that they were using ASL at home and that children were exposed to ASL before 36 months of age.

We recruited 69 children to participate in one or both experiments. Of the recruited sample, 12 children did not complete any trials in the eye-tracking task. In total, 57 children completed 64 eye-tracking sessions: 25 completed only Experiment A, 25 completed only Experiment B, and 7 completed both experiments (with at least six months in between testing sessions). Of these, five participants were tested but later excluded for excessive track loss (defined in **Data Processing**, below).

Thus, the final sample includes 52 children (18–71 months, M_{age} = 47.26 months) who completed 59 eye-tracking sessions. For the participants who completed both experiments, both sessions were retained. Of participants that were included in the analysis, 48 children had deaf parents, and 8 children had hearing parents. Although most deaf children are born to hearing parents, the high proportion of deaf caregivers in our sample likely reflects both our inclusion criteria (children primarily using ASL) and our recruitment pathways.

Parents completed an extensive language background questionnaire and a subset of parents ($n = 27$) completed a parent-report vocabulary measure, the ASL-CDI 2.0 (Caselli et al., 2020). Participant demographics are summarized in Table 1 and Fig. 1.

Table 1
Demographic characteristics of participants. For continuous variables, range and mean are provided. For categorical variables, percentages by level are provided.

Variable	Distribution
N	59
Age (months)	18–71, 45.1 (15.2)
Primary Caregiver Hearing Status	Deaf / Hard-of-Hearing: 86%
	Hearing: 14%
Age exposed to ASL (months)	0–36, 2.4 (7.8)
CDI Vocabulary %	0–1, 0.8 (0.2)
Sex	Female: 29%
	Male: 68%
Race	African American/Black: 0%
	Asian: 2%
	More than one: 7%
	White: 79%
	Unknown: 12%
Ethnicity	Hispanic or Latino: 20%
	Not Hispanic or Latino: 75%
	Unknown: 5%

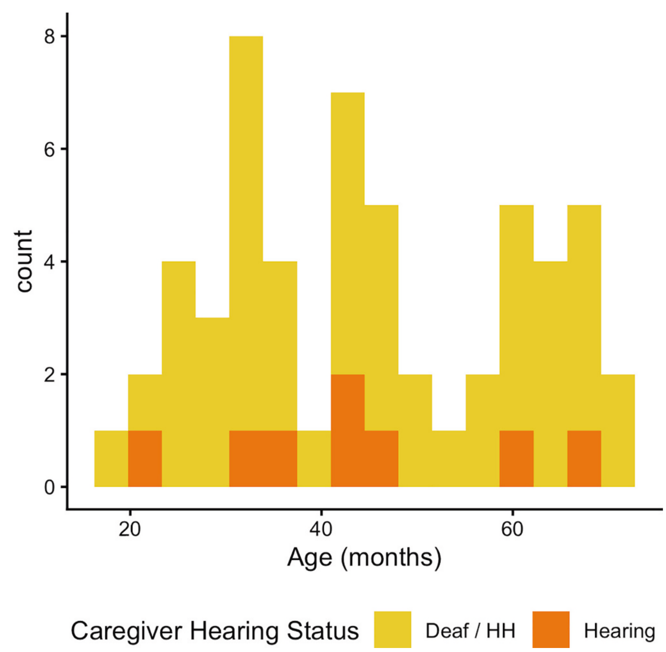

Fig. 1. The age distribution of participants in our sample.

3.2. Eyetracking Set-up

Parents and children were seated in front of a monitor and an SR-Research Eyelink 1000+ eye-tracker which recorded eye movements at 500 Hz. Children either sat on their parent's lap or on a booster seat. Parents were instructed not to direct their child's gaze in any way. The monitor for Experiment A was 17 in., and the monitor for Experiment B was 24 in.. A short, animated movie was played to attract the child's attention while the experimenter affixed a small sticker on the child's forehead and focused the camera. Next, a five-point calibration sequence was carried out.

3.3. Experiment

Experiments A & B were designed to measure deaf children's fast mapping of novel signs and to determine how the timing of referential cues during exposure to novel signs predicted children's ability to fast-map those signs to novel objects (Lieberman et al., 2022). These experiments consisted of two phases: an exposure phase and a test phase. Children saw two (Experiment A) or three (Experiment B) blocks; each block consisted of eight exposure trials followed by eight test trials. The experiments were identical in their test phases and only differed in the exposure phases. We focus just on the test phase in the current analysis but briefly describe the exposure phase for context.

Exposure Phase (not analyzed here). During the exposure phase, participants viewed a picture of a novel object and a signed label for it. Lieberman et al. (2022) compared fast-mapping of novel nouns across different exposure conditions: specifically, the signer varied whether and when gaze and/or point cues were presented along with the novel word label. In addition, Experiments A and B differed in the number of objects on the screen during exposure (one object in Experiment A, two objects in Experiment B). Regardless of exposure condition, each novel object was labeled four times (twice in each of two trials during the exposure phase). During each exposure trial (see Fig. 2), participants saw a novel object, then a labelling video where a signer signed "ATTENTION-GETTER POINT WHAT? NOOP. COOL! POINT WHAT? NOOP." (*"Hey, what's that? A noop. Cool! What's that? A noop"*). The authors found that children were highly successful at learning the novel words, and that ultimately fast mapping performance did not vary across exposure conditions. For our analysis of behavior during the test trials, we collapse across exposure conditions and experiments. In addition to the novel words, there were also trials in which *familiar* words were presented in the same format; half of the familiar words appeared as filler trials during this exposure phase.

Test Phase (analyzed here). In the test trials, participants were tested on their ability to recognize the novel signs, and for comparison, familiar signs. Pairs of pictures consisting of a target and distractor first appeared on each side in the lower quadrant of the screen (see Fig. 2 for illustration). Next, a fixation cross appeared centered in the top half of the screen. The cross was gaze-contingent, such that when children fixated on the cross, this triggered the onset of the video. The test video then played, during which a signer said “WHERE [target word]?”; children were not given any instructions beyond this signed video prompt. During the test video, the images remained on screen, and if the child was fixating on the signer, the images were within 15–20 degrees of visual angle. After the video ended, the video disappeared and the images remained on the screen for an additional 2000 ms period, after which the experimenter would press any key on the keyboard to advance to the next trial. This key press was built in to prevent the experiment from advancing automatically to the next trial, in case the child was

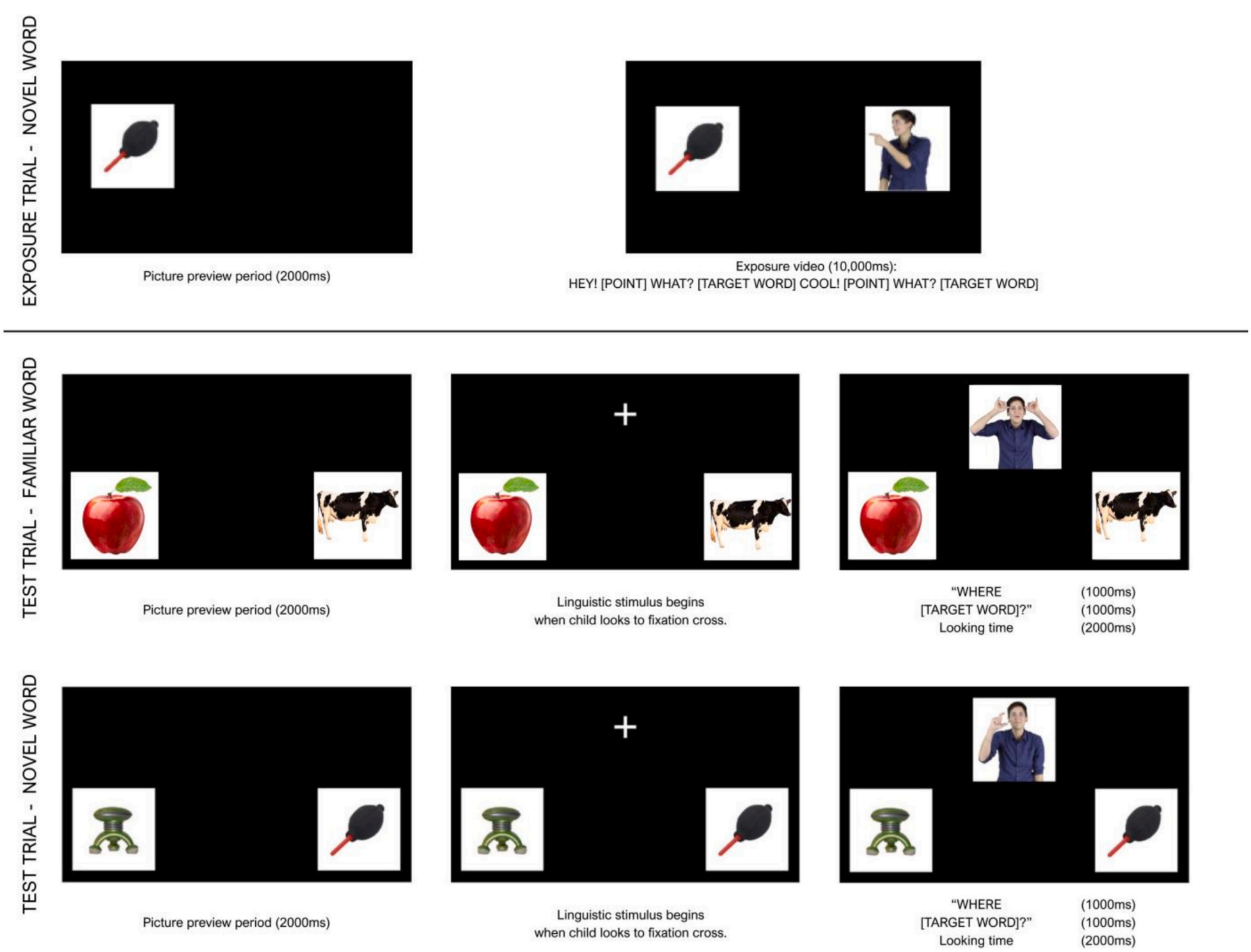

Fig. 2. Examples of (from top to bottom): a novel word exposure trial, a familiar word.

clearly looking away from the monitor. Within the experiment itself, there were animations to keep children's attention on the task, e.g. an animated dot to direct attention to the center of the screen before each trial started. If the child began to lose attention during the task, then the experimenter would use ASL signs (e.g. LOOK!) or other encouragement to bring the child's gaze back to the screen.

Each experimental block included four familiar and four novel word recognition trials; there were three blocks in Experiment A and two blocks in Experiment B. Thus, each child completed up to 8 or 12 familiar word recognition trials and up to 8 or 12 novel word recognition trials in total.

3.4. Stimuli

The test video stimuli were identical across conditions and experiments. The video consisted of the signer producing the two-sign sentence "WHERE [OBJECT]?", e.g. "WHERE APPLE?" ("Where is the apple?"). Stimuli were edited so that the WHERE sign was exactly 1000 ms and the object label was 1000 ms. The onset of the target sign was identified as the first frame when the signer's hand transitioned away from the final movement of the WHERE sign. The videos were 400 × 400 pixels (4 in. square) with the signer appearing against a white background.

Objects in the familiar word trials were chosen to represent signs that are commonly acquired early. Words were presented in yoked pairs; pairs were chosen to minimize ASL phonological similarity in the yoked signs, and each word in the pair came from a different semantic category (e.g. animals, food, vehicles, and other household objects). Each object appeared equally as a target and distractor. See Supplemental Materials (Tables S1 & S2) for stimuli details.

3.5. Data processing

We excluded trials where the participant was looking off-screen or did not have a detectable track for more than 80% of the trial, resulting in the exclusion of 11.8% of trials for Experiment A and 8.1% of trials for Experiment B. After combining data from the two experiments, we also excluded trials where the participant did not look at all to the signer during presentation of the target word (11.89% of trials). Lastly, we excluded participants who had usable data on fewer than 25% of the familiar word trials (i.e., at least 3 familiar word trials in Experiment A or at least 2 familiar word trials in Experiment B), resulting in the exclusion of five participants.

Accuracy on both familiar and novel word trials was operationalized as the log-transformed ratio of looking to the target image relative to the distractor image during our time window of interest (600-2500 ms after target word onset,). This time window was informed by prior work showing that signers typically maintain gaze on the signer for several hundred milliseconds before shifting to the referent (Lieberman et al., 2022; MacDonald et al., 2018). The log-ratio of target looking is a common measure of word recognition accuracy (e.g., Csibra et al., 2016; Ito & Knoeferle, 2023), which is designed to address analytical challenges with eye-tracking data.[1]

We operationalized reaction time as the number of milliseconds from the onset of the target sign until the child launched a saccade to one of the pictures. We intentionally counted looks to both the target image and looks to the distractor image because we wanted to keep accuracy separate from speed. Rather than counting how quickly participants oriented to the target image, which is necessarily confounded by accuracy, we measured how quickly children oriented away from the signer to one of the images.[2]

4. Results

All analyses were conducted in R, and data and code for these analyses are available on OSF. These analyses were not pre-registered. We first characterize age-related differences in familiar word recognition in deaf children learning ASL, assessing how speed and accuracy vary across early childhood. We then ask whether children's familiar word recognition is related to their behavior in a fast-mapping task.

Because seven children participated in both experiments at sessions several months apart, we treated these as repeated observations and accounted for this dependency with a random effect for participant and a fixed effect of age (in months, rounded to the nearest month). For all analyses, we start with the most complex random effects structure with random effects for subject, target word, and experiment, but in many cases, the models did not converge or exhibited singular fit. When that happened, we simplified the random effects structure[3] until the model converged with no issues.

4.1. Does familiar word recognition change across age?

Children showed high overall accuracy on this task; see Fig. 3. On 63.83% of trials, children looked more to the target image than to the distractor image. This varied minimally across words, with the exception of MILK, which was determined to be much less visually interesting than its yoked pair (BEAR) and was replaced after the first three participants didn't look to the picture of milk at all during the test trials; see Fig. S1 in Supplementals. Accuracy did not differ by experiment, nor by whether the familiar sign appeared during the exposure phase ($ps > 0.05$).

To measure how accuracy varies across age, we conducted a linear mixed effects model predicting the proportion of looking to the target image during our window of analysis (600-2500 ms after target word onset), with a main effect of age[4] (measured in months) and a random effect for participant. We found that older children looked increasingly more to the target image ($t = 2.87$, $p = .006$); see Fig. 4 and Table 2.

Participants' first look to an image occurred 6–3636 milliseconds after target word onset (M: 1346.26, (SD:683.26)). This suggests that on average, participants looked to the signer for the entirety of the target sign video (1000 ms) before shifting their gaze to the pictures. Reaction time did not differ by experiment, nor by whether the familiar sign appeared during the exposure phase ($ps > 0.05$). See Supplementals (Fig. S1) for item-level reaction times.

Next, we measured whether reaction time changed across age. Here again, we fit a linear mixed effects model with a main effect of age and random effects for participant and for experiment. We did not find a main effect of age ($t = -0.76$, $p = .451$); that is, older children in our sample were not significantly faster to launch a saccade to the images than younger children; see Table 3 and Fig. 4. We additionally tested

[1] Raw proportions of looking time are not linearly independent (i.e. greater looks to one AOI necessarily means fewer looks to other AOIs). Additionally, raw proportions violate homogeneity of variance assumptions, because proportions are inherently fixed between zero and one.

[2] If we instead measure reaction time as the time between onset of the target word and the first time the child looked to the target image (not counting distractor image looks), we find the same pattern of results.

[3] To simplify the random effects structure, we would first remove the random effect for target word, then experiment, then subject, until the model converged without issue.

[4] A subset of caregivers ($n = 27$) completed the ASL-CDI 2.0 a parent-report measure of vocabulary (Caselli et al., 2020). We ran this model (and our other age models) with a main effect of productive vocabulary size instead of age. We fit separate models for age and vocabulary due to the strong correlation between age and vocabulary ($R_{Pearson's} = 0.68$, $p < .001$). Vocabulary did not explain significant variance in any of the models. We suspect that this is due to data sparsity (some parents did not complete the measure and were thus not included in the vocabulary models) and possible ceiling effects (nearly a quarter of participants scored above 90% accuracy on the ASL-CDI).

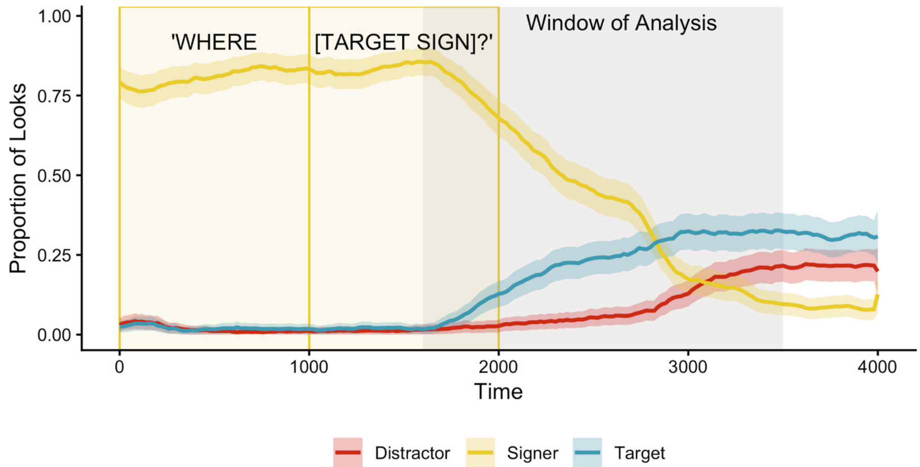

Fig. 3. Timecourse of gaze behavior on familiar word test trials, averaged across all participants. Yellow shading depicts timing of linguistic stimuli, and grey shading depicts the window of analysis (600-2500 ms after target sign onset). For visualization, the y-axis is in raw proportion of fixations to the signer, target image, and distractor image, but note that all analyses were conducted on the log-transformed ratio of target vs. distractor looks. Error band depicts 95% CI which has been Bonferroni-corrected for multiple intervals (Porretta et al., 2020). (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this article.)

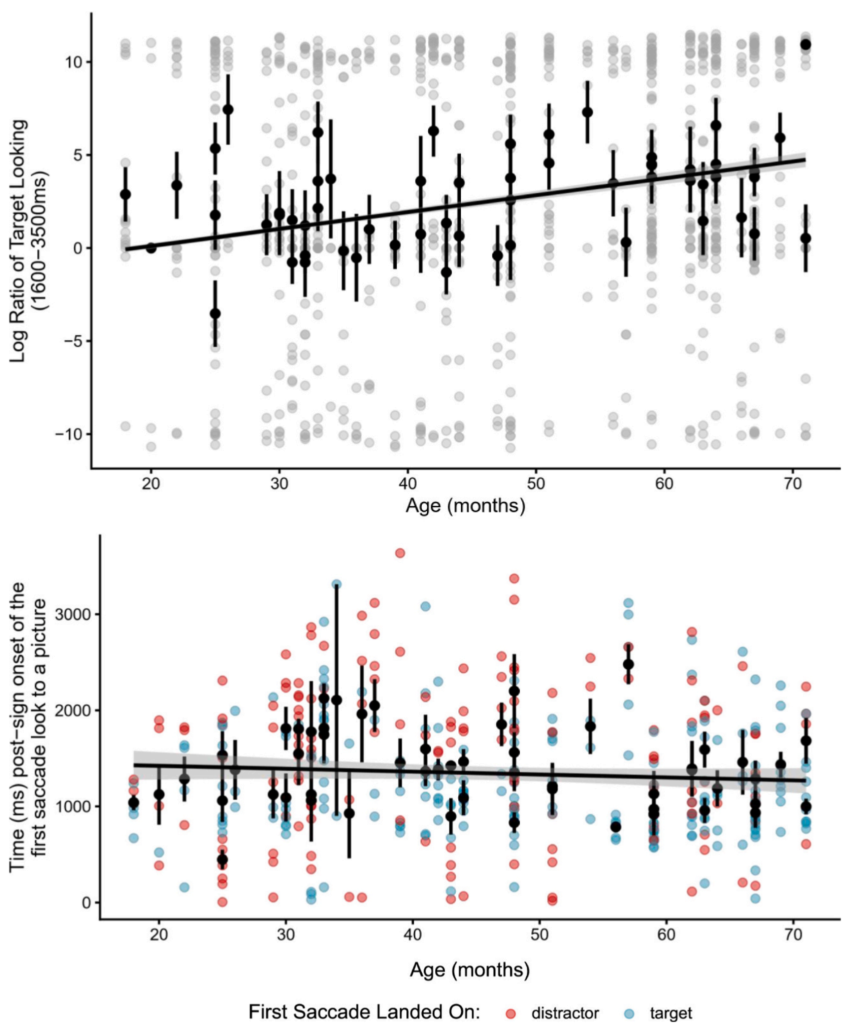

Fig. 4. Top: Proportion of target looking to the familiar word, by participant age. Window of analysis is 600-2500 ms after target sign onset. Bottom: Timing of first saccade away from the signer towards object images, by participant age. Each dot represents looking behavior for one trial for one participant.

whether reaction time might vary *non*-linearly as a function of age, but did not find evidence for a relationship between reaction time and age (see Supplemental Materials Fig. S2). We next tested *where* the child's first saccade landed, i.e. on the target or distractor picture, and calculated, for each child, the proportion of trials in which their first saccade away from the signer landed on the correct image. Here, we found that

Table 2
Model results for predicting children's accuracy as a function of age: Log(Ratio of Target:Distractor Looking) = Age + (1|Subject) + (1|Experiment) + (1|Item).

Effect	Beta	Standard Error	t	df	p
Intercept	−0.03	1.34	−0.02	50.38	0.983
Age (months)	0.08	0.03	2.87	46.39	0.006

Table 3
Saccade Time = Age + (1|Subject) + (1|Experiment) + (1|Item).

Effect	Beta	Standard Error	t	df	p
Intercept	1473.50	213.95	6.89	4.06	0.002
Age (months)	−2.52	3.32	−0.76	48.05	0.451

older children's first saccades were increasingly accurate ($R_{Spearman's} = 0.35$, $p = .009$). Thus, although the point at which the firset saccade happened was stable across age, older children's first saccade was more likely than younger children's to land on the target image.

4.2. Does familiar word processing predict novel word learning?

Our second goal was to determine if familiar word recognition relates to fast-mapping of novel signs. To examine within-participant relationships, we averaged accuracy and reaction time across trials for each child and analyzed these participant-level measures using linear models (without random effects).

We asked whether children's speed of familiar word recognition predicted their looking behavior on the novel word task. Here, we took children's average reaction time on the familiar word trials and used it to predict their accuracy on novel word trials, while controlling for age. We found that children who were faster on familiar word trials were more accurate on novel word trials ($B = -0.0017$, $p = .035$); see Table 4 and Fig. 5.

To further understand how familiar and novel word learning relate to one another, we compared accuracy on familiar and novel test trials. Accuracy on familiar word trials was strongly correlated with accuracy on novel word trials (as measured by the log ratio of target looking; $R_{Pearson's} = 0.49$, $p < .001$). Children who looked more to the target (vs. distractor) image on familiar word trials also looked more to the target image during the novel word test trials. Both familiar word accuracy (as shown above) and novel word accuracy ($B = 0.06$, $p < .001$) were positively associated with age, and children were more accurate on familiar word recognition than on novel word recognition ($B = 1.71$, $p = .002$); see Table 5. There was no interaction between word type and age. We summarize the full set of within-subject relationships among age, our familiar word gaze measures, and novel word learning in Figure 6.

5. Discussion

We investigated the development of familiar word recognition among deaf children learning ASL and the relationship between familiar word recognition and novel word learning. First, we replicated prior evidence that older children are more accurate than younger children in recognizing familiar words (MacDonald et al., 2018), suggesting a similar developmental trajectory in ASL as has been observed for spoken

Table 4
log(Ratio of Target:Distractor Looking) (on novel trials) = Saccade Time (on familiar trials) + Age.

Effect	Beta	Standard Error	t	p
Intercept	2.68	1.514	1.77	0.082
Saccade time (ms) on familiar trials	0.00	0.001	−2.17	0.035
Age (months)	0.03	0.021	1.64	0.107

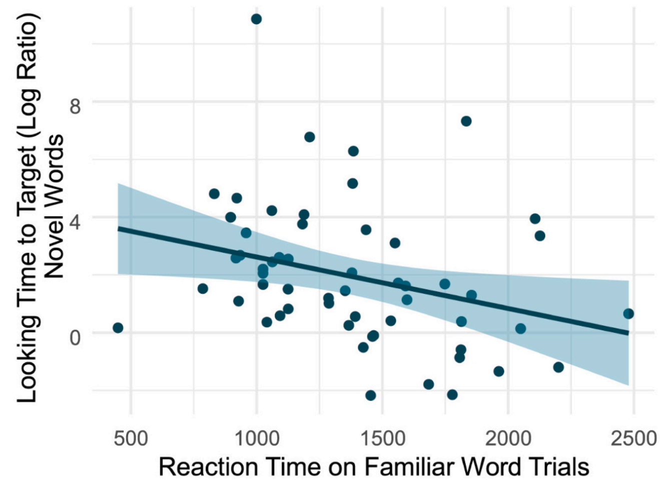

Fig. 5. Relationship between reaction time on familiar word trials (operationalized as the speed of first saccade to one of the pictures) and accuracy on novel word trials. Each dot represents one child's looking behavior, aggregated across trials.

Table 5
log(Ratio of Target:Distractor Looking) = Trial Type (familiar or novel) + Age.

Effect	Beta	Standard Error	t	p
Intercept	−0.82	0.903	−0.91	0.367
Trial type (Familiar)	1.71	0.542	3.15	0.002
Age (months)	0.06	0.018	3.39	< 0.001

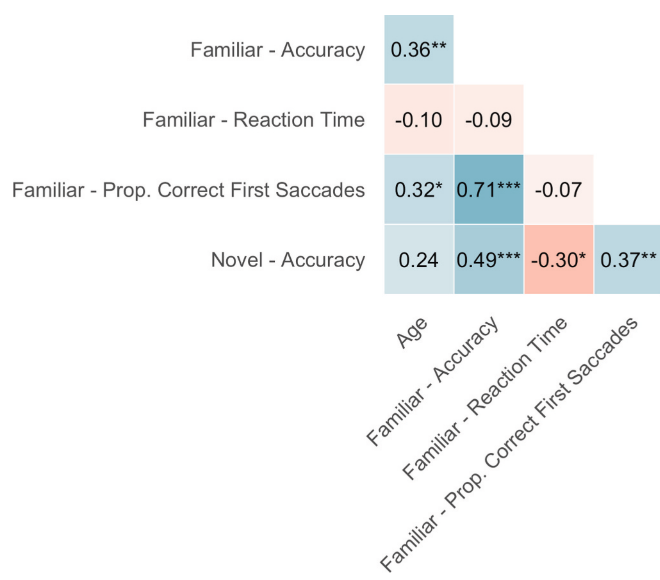

Fig. 6. Correlation matrix with relationships among age, each of our familiar word variables, and children's accuracy on novel word trials. Correlation coefficients represent zero-order Pearson's correlations between variables. Asterisks indicate significance level (* = $p < .05$; ** = $p < .01$, *** = $p < .001$). Color represents the direction of the correlation (positive vs negative).

language (Frank et al., 2025). We then explored the relationship between familiar word recognition and novel word learning. As expected, participants were faster and more accurate to recognize familiar words than recently-learned novel words. Crucially, children who were faster and more accurate to recognize known words were *also* more accurate at novel word recognition, paralleling findings from spoken language development (Lany, 2018; Ronfard et al., 2022) and suggesting a robust link between processing and learning mechanisms across modalities.

5.1. ASL word recognition improves across development

The ability to quickly and accurately recognize a familiar word allows children to take advantage of ongoing language input (Weisleder & Fernald, 2013). For children learning a signed language, allocating visual attention to a referent may involve some additional calculation compared to spoken language. Although caregivers may sometimes scaffold interactions for young children, for example by bringing signs into the child's line of vision or bringing objects up near their face so that children can perceive both the object and sign simultaneously (Beatrijs et al., 2019; Swisher, 1999), this is not always the case. In many instances, children must alternate attention between the linguistic input (visually fixating on the signer), or the referent of the sign (visually fixating on an object) (Lieberman et al., 2014). This aspect of perception in sign language interactions requires children to make in-the-moment decisions about where to direct their visual attention. In the current sample, children's accuracy on familiar sign recognition increased with age, reflecting greater success in mapping signs to referents in situations that require shifting visual attention between the signer and the environment.

Contrary to our expectations, age was not a significant predictor of word recognition efficiency (though c.f., MacDonald et al., 2018). Across our age range, children continued fixating on the signer for most of the sign, launching a saccade away from the signer towards the end of the sign. This aligns with corpus evidence that when children perceive a sign during interaction with a parent, they rarely look away in the middle of an unfolding sign (Gappmayr et al., 2026). Participants' persistent gaze to the signer diverges from spoken language results, where children shift their gaze to the referent almost immediately (Fernald et al., 1998; Fernald et al., 2001). This language-modality difference in looking behavior suggests that children acquiring ASL are adaptive to the attentional demands of perceiving linguistic input visually and maintain attention to a signer as long as information is actively unfolding (MacDonald et al., 2020). However, children's first saccade accuracy improved with age: older children were more likely than younger children to land on the target word once they shifted gaze away from the signer. Thus, although we cannot ascertain what processing strategies children are using while perceiving unfolding signs, we do see a developmental change in their success in mapping signs to correct referents. We speculate that older children may be improving at the in-the-moment decision making about when and where to allocate their attention while perceiving unfolding input.

Across the toddler years and early childhood, children are also improving in working memory (Reynolds et al., 2022), peripheral vision (Codina et al., 2011), and managing covert visual attention (Hendry et al., 2019). These developments could support children's performance on the task, but are perhaps less directly related to their word knowledge. For example, in our dataset, we observe that the accuracy of deaf children's first saccade (whether they first land on the target or distractor image after disengaging from the signer) is correlated with age, but this improvement could be due to older children's better memory for the images (which they saw in the preview period) or due to older children's better ability to perceive and attend to the images in peripheral vision while watching the signed stimuli. These are fruitful areas for future research.

Although we did not observe age-related changes in processing speed among children in our study, older children (Lieberman & Borovsky, 2020) and adults (Lieberman et al., 2015; MacDonald et al., 2018) can use partial information about an unfolding sign to identify its referent. It may be the case that the age range of children in our current sample did not capture inflectional moments in the developmental trajectory of sign processing efficiency. These developmental differences might reflect young children's need for more complete phonological information than adults (Corbin et al., 2016; Eisenberg et al., 2000). Alternatively, processing speed might be a reflection of stable cognitive traits, language experience, or moment-to-moment task demands (McMurray et al., 2012), but future work is required to disentangle these possibilities.

In naturalistic contexts, the attentional tradeoff between linguistic and referential information may make sign language word learning more dependent than spoken language word learning on clear referential cues (e.g., points, pauses, sign location) and well-timed gaze-shifting. Importantly, among families using ASL, both deaf children and their parents appear adept at navigating this visual attention dance. Infants with early sign language exposure show gaze behavior that is highly attuned to sign language perception as young as six months (Bosworth & Stone, 2021). Parents are sensitive to their child's attentional focus and often time their signed input to coincide with moments when the child is visually engaged (; Gappmayr et al., 2026; Harris et al., 1989; Sander et al., 2025; Swisher, 1999). When children are not attending, parents use attention-getting strategies (such as waving, tapping, or moving the sign into the child's field of view) to redirect gaze towards the linguistic signal. Children, in turn, frequently shift visual attention between the signer and the referent by both responding to caregiver prompts and through spontaneous shifts in attention (Sander, Rowland and Lieberman, 2025). Deaf children's gaze behavior during naturalistic interaction suggests that the proportion of caregiver signs that children perceive increases across early childhood (Gappmayr et al., 2026).

5.2. Mechanisms for a processing—learning link across modalities

In spoken language, faster familiar word recognition is linked to vocabulary growth (Fernald & Marchman, 2012; Frank et al., 2025; Lany, 2018), and cognitive and linguistic abilities later in childhood (Marchman & Fernald, 2008). In our sample too, we found that children who were faster to look towards a labeled, known object were more successful in fast-mapping novel words. In addition, overall accuracy, as well as accuracy of the first saccade in familiar word trials, was correlated with accuracy on the novel word trials. Despite the fact that mapping signs to referents requires skilled and carefully-timed allocation of visual attention, our findings suggest broad similarities in word recognition patterns across modalities.

While our results do not allow us to pinpoint a single mechanism underlying the processing-learning relationship, they do illustrate that there are modality-independent factors supporting children's ability to leverage real-time processing skill for vocabulary acquisition. One possible explanation is that rapid processing of familiar wordforms enables children to direct cognitive and attentional resources to novel lexical items and to information in the surrounding visual scene. Specifically, children who processed familiar signs more quickly may have been better able to shift their gaze flexibly or anticipatorily in service of referential mapping. In more naturalistic signing contexts—where signs appear in continuous utterances and additional semantic information is available—quick recognition of a wordform could allow children to redirect their attention to contextual cues, such as following the gaze of their interlocutor. Indeed, by the end of their first year, deaf infants with early sign language exposure follow the referential gaze of a caregiver more accurately than non-signing hearing children (Brooks et al., 2020). Thus, children who can identify a wordform quickly and initiate a gaze shift early may be better positioned to link novel forms to meaning.

Rapid word recognition could also directly facilitate learning by helping children resolve referential ambiguity through word learning constraints such as mutual exclusivity, in which children assume a novel label applies to an unlabeled object (Fitch & Lieberman, 2025; Markman, 1990). Quickly eliminating alternative referent candidates would allow children to fixate on the correct referent and encode the word–object pairing. Efficient familiar word recognition may also provide semantic context for an upcoming novel word (Jones et al., 2020), enabling children to anticipate the likely referent and integrate new information more efficiently than would be possible without that semantic context. By this account, children learning sign language should similarly be able to leverage semantic context to anticipate referents. These skills may then participate in a positive feedback loop, wherein word recognition supports vocabulary growth, and a larger vocabulary in turn supports more efficient word recognition (Meylan & Bergelson, 2022).

Importantly, our results cannot adjudicate between causal and non-causal relationships between processing and learning. The correlation between efficient familiar word recognition and successful word learning could reflect a shared set of underlying skills (McMurray et al., 2012). Namely, robust phonological processing skills, adept attention management, and rapid lexical retrieval could enable rapid word identification while also supporting the encoding of new forms. By this account, both word recognition and word learning involve a mapping between incoming lexical information and existing representations of words in the mental lexicon. Our findings are similarly consistent with these explanations.

5.3. Future directions

While we show clear evidence for the relationship between lexical processing and fast-mapping of novel words to their referents, we did not directly test the retention of novel words over time, and this is an area for further investigation. It is possible that the underlying cognitive skills supporting the immediate mapping of novel words to novel objects are uniquely supported by the ability to quickly process familiar signs. However, given the parallels observed here with prior studies of spoken language learning, in which fast-mapped words are retained across increasingly long delays as children get older (e.g., Bion et al., 2013), we speculate that processing this relationship would hold for sign retention as well. Our results suggest that processing speed during familiar word recognition could support at least these initial fast-mappings.

The current study also leaves open questions about the nature of lexical development among young deaf children learning ASL. Specifically, we cannot disambiguate whether children's gaze behavior is driven by their deafness or early sign language exposure. Our study included hearing caregivers and deaf caregivers, but all children were learning ASL as their primary language and had been exposed to ASL early in life. Deaf children's language input, however, is highly diverse, with families using spoken language, sign language, invented sign systems (e.g., Signed Exact English, cued speech), or a combination thereof (Hall & De Anda, 2022). In environments where sign language exposure is more intermittent, or where signs and speech are used simultaneously, the temporal and spatial alignment between language and referents may be less consistent, making it more difficult for children to extract reliable form-meaning mappings or to learn when and where to direct their gaze. Results from hearing children of deaf parents (MacDonald et al., 2018) suggest that sign language exposure, and not deafness, gives rise to the observed patterns of word recognition, but we look to future research to explore how the quantity and quality of early sign input impacts early learning.

6. Conclusion

Our analyses explored the developmental trajectory of familiar word processing in deaf children learning ASL. We identified both parallels and divergences from patterns of spoken word recognition. Overall, word recognition in both sign and spoken language improves across toddlerhood, as children gain more experience interacting with others and with the world. In addition, like in spoken language, signing children who are more efficient in recognizing familiar words were also better at fast-mapping novel signs to novel objects. On the moment-to-moment level, however, word recognition in sign language looks slightly different from word recognition in spoken language, in that toddlers learning ASL perceive signs in their entirety before shifting attention to the referent object. In the visual modality, accessing linguistic and referential cues requires deliberate, sequential shifts in gaze, and perhaps consequently, children in our sample tended to wait until the end of the linguistic information before directing attention elsewhere. Together, these findings suggest that the way deaf children manage visual attention when processing familiar signs may scaffold their success in acquiring new vocabulary. By characterizing the developmental trajectory of real-time word recognition and its relationship to novel word learning, this study contributes to a growing understanding of how deaf children leverage visual attention to build a lexicon, and broadens the empirical foundation of existing accounts of word learning to include a wider range of sensory experiences.

CRediT authorship contribution statement

Erin Campbell: Writing – review & editing, Writing – original draft, Visualization, Project administration, Formal analysis, Conceptualization. **Michael Higgins:** Writing – review & editing, Formal analysis. **Allison Fitch:** Writing – review & editing, Investigation. **Arielle Borovsky:** Writing – review & editing, Formal analysis. **Amy M. Lieberman:** Writing – review & editing, Writing – original draft, Supervision, Resources, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

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Declaration of competing interest

The authors have no conflicts of interest to report.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cognition.2026.106499.

Data availability

All data and code for this study are available on OSF.

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