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American Sign Language basic clause comprehension strategies used by late first-language learners: plausibility, animacy, and linguistic structure

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ABSTRACT

Few studies to date have explored the role of early language experience on syntactic development during the early stages of language acquisition. Understanding the language outcomes of deaf individuals with severely delayed first language (L1) onset can provide valuable insights into the nature of the critical period for early syntactic development. The current study examines the use of linguistic versus extra-linguistic (plausibility, animacy) cues at the basic clausal level by deaf late L1 signers of American Sign Language (ASL). Nine late L1 signers of ASL completed a sentence-picture matching task involving sentences that varied in linguistic structure, plausibility, and noun animacy. Overall, late L1 signers tended to rely on linguistic cues in noun-attribute and spatial classifier sentences even when the sentence meanings were implausible. In contrast, when faced with implausible and irreversible transitive sentences, they showed resilient but fragile use of word order, with overall high accuracy except when animacy conflicted with word order. These comprehension patterns resemble those of young children with an immersive early language environment, who often rely on a mix of linguistic and extra-linguistic cues before robustly relying on linguistic rules. Together, these findings suggest that late L1 signers exhibit a graded representation of basic syntactic structures, emphasizing the critical role of early language exposure in fostering the robust development of basic clausal structures.

Introduction

One hallmark of human language is its productivity (Hockett, 1959). By combining linguistic units in meaningful ways following language-specific rules, we can generate novel, sometimes even absurd meanings, for example, "a banana is biting a boy". Between the ages of three to five, young children who are immersed in a language-rich environment gradually learn to robustly rely on language-specific structures such as basic word order to guide transitive sentence interpretation (Candan et al., 2012; Chan et al., 2009, 2010; Chapman & Miller, 1975; Lindner, 2003; Slobin & Bever, 1982; Strohner & Nelson, 1974). Such robust use of linguistic cues at the basic clause level increases the intake of linguistic information during syntactic development (Omaki & Lidz, 2015) and allows for syntactic bootstrapping (Fisher et al., 2010; Gertner et al., 2006; Naigles, 1990), which is crucial for subsequent learning of new verbs with embedded structures (Harrigan et al., 2019; Naigles, 1996; Papafragou et al., 2007).

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The role of early language experience on early syntactic development remains unclear, however. Deaf children with no formal language input often develop their own gestural systems (homesigns) with consistent order patterns based on semantic roles (Coppola & Newport, 2005; Goldin-Meadow et al., 2015), suggesting budding linguistic structures even with minimal language input. However, case studies of deaf late first language (L1) learners of American Sign Language (ASL) suggest that when the learner's early environment contains minimal language input, even basic clause structures might not fully develop (Cheng & Mayberry, 2021; Mayberry et al., 2023). In the current study, we aim to further examine the nature of this early syntactic development and ask how linguistic versus extra-linguistic (plausibility, animacy) cues influence ASL comprehension at the basic clause level in adults whose language development began after early childhood.

Studies of language development in this population can illuminate how early language experience shapes human language learning and processing capacity. Such naturalistic information is difficult to obtain elsewhere given the rich language environment of most typically developing children. Moreover, given the pervasive risk of early language deprivation among deaf children with variable early language environments, an increased understanding of the characteristics of their language learning and processing outcomes can help identify and better support deaf children and adults who experienced reduced language input in early life.

Many studies have revealed a relation between the quality and quantity of early language experience and the rate of language development among typically developing children. An increased amount and complexity of early language input contributes to faster early vocabulary development (Ferjan Ramírez et al., 2020; Fernald et al., 2013; Huttenlocher, 1998; Huttenlocher et al., 1991; Rowe, 2012), as well as the use of complex syntactic structures (Huttenlocher et al., 2002; Vasilyeva et al., 2008). Still, early syntactic milestones do not seem to be much affected by the quantity or quality of language input. Children show a similar developmental trajectory beginning with simple sentence types regardless of their socio-economic background, which is often associated with the amount of language input children receive (Vasilyeva et al., 2008). Mayan children, with a different type of language input (e.g., less child-directed speech from parental input) (Shneidman & Goldin-Meadow, 2012), show an early syntactic development trajectory similar to that of Western children who receive much more child-directed speech (Casillas et al., 2020).

One of the early syntactic milestones in many languages is the use of basic word order. Young children learning a spoken or sign language from birth often show early sensitivity to word order in production around two years of age, in both spontaneous and elicited tasks (Brown, 1973; Chapman & Miller, 1975; Chen Pichler, 2002). At this age, children sometimes perform at chance level in acting-out tasks with reversible Animate–Animate combinations (E. Bates et al., 1984; Strohner & Nelson, 1974; Thal & Flores, 2001), but in less demanding tasks such as preferential looking paradigms, they demonstrate adequate use of word order especially with familiar verbs (Chan et al., 2010). These findings suggest gradually developing linguistic representations. Between the ages of two to three, studies on English-speaking children show reliance on both word order and animacy when comprehending transitive SVO sentences; they perform with higher accuracy for Animate-Inanimate than Animate–Animate combinations but are at chance with Inanimate-Animate combinations (Chapman & Miller, 1975; Strohner & Nelson, 1974).

The use of animacy and word order also interacts with event probability, with a strong bias toward probable events (Strohner & Nelson, 1974), even when the subject is animate (Chapman & Kohn, 1978). A cross-linguistic study of Cantonese, German, and English-speaking two-and-half-year-olds found them all to show overall lower performance in inanimate-animate combinations, while older children (3;6 and 4;6) consistently relied on word order regardless of the subject/object animacy (Chan et al., 2009). Still, Cantonese-speaking children were more influenced by animacy at older ages (Inanimate-Animacy accuracy around 80% at age 4;6), likely due to the less reliable syntactic cues in Cantonese given its word order variations and null arguments in natural discourse. From a graded representations view of syntactic development (Abbot-Smith & Tomasello, 2006), younger children

first develop a less robust representation of basic word order, one that is weak and susceptible to influence from subject/object animacy, event plausibility, and task demands. Given the high overlap between animacy, agenthood, and the first noun in early language input, young children often adopt a first-noun-as-agent strategy during sentence comprehension (Abbot-Smith et al., 2017; E. Bates et al., 1982; Gertner & Fisher, 2012; Gertner et al., 2006; Slobin & Bever, 1982).

Deaf babies are at a high risk of insufficient early language input. The predominant spoken language of the environment is often less accessible to deaf babies. Even with the use of hearing technologies such as hearing aids or cochlear implants, the amount of spoken language input they can perceive is often limited and highly varied, leading to great variation in language outcomes (Carrigan & Coppola, 2020; Daub et al., 2017). At the same time, sign language uses the visual-manual modality and is fully accessible to deaf babies, but it is not always present in the environment. Less than 10% of deaf babies have signing parents (Mitchell & Karchmer, 2004). Most deaf babies have varied amounts of spoken and sign language exposure, and are at risk of early language deprivation (W. Hall, 2017).

In some cases, deaf individuals experience minimal early sign and spoken language support and are isolated from the deaf community, and they eventually learn a sign language as their first functional language later in life (Mayberry & Kluender, 2018). We describe these signers as late L1 signers, with the following working definition: 1) experience minimal functional language input before puberty, which is considered the critical period for first language learning (Lenneberg, 1967; Mayberry & Kluender, 2018, but also see Hartshorne et al., 2018 for second language learning); 2) have full immersion in a natural sign language environment once they are introduced to it; 3) use the sign language as their main mode of communication. Studies of this developmental circumstance show that some linguistic structures appear to develop even when language in the early environment is sparse. Deaf home signers who develop their own gestural systems often show consistent order patterns based on semantic roles (Coppola & Newport, 2005; Goldin-Meadow et al., 2015), but they often express only one event participant in their gestural combinations. When exposed to a sign language in adolescence, three late deaf L1 learners showed typical and rapid vocabulary development (Ferjan Ramírez et al., 2013). Another study with four late deaf L1 signers found consistent use of canonical word order in spontaneous ASL production (the Subject-Verb, SV, or the Verb-Object, VO, order) after two to three years of ASL exposure, but also primarily with one event participant (Cheng & Mayberry, 2019). Another study with two late L1 signers found a rapid shift from using home signs to using ASL signs with spatial inflections as well as classifier predicates within 31 months of ASL exposure in a school setting (Morford, 2003). The years of language experience required for developing these linguistic skills for late L1 signers are close to or shorter than those required for children acquiring the language from birth (Anderson & Reilly, 2002; Chen Pichler, 2002; Kantor, 1980; Meier, 1987). Still, despite the initial rapid development of spatial structure in production, after 7 years of ASL exposure, their comprehension of those structures remained near chance when the processing load was high (Morford, 2003).

A parametric study of late L1 signers' sentence comprehension found the majority to perform well on the ASL basic structures of intransitive Subject-Verb and one-agent semantic classifier constructions (Mayberry et al., 2023). However, their performance on sentences with two arguments requiring knowledge of basic word order, transitive Subject-Verb-Object (SVO), was mostly at chance level. Analyses of the same participants' signed production elicited with pictures showed that the majority of their utterances consisted of one participant, or argument, per verb. Their two-argument productions were sensitive to semantic aspects such as the animacy of the arguments (Miles et al., 2024). Incomplete development at the morpho-syntactic level has been repeatedly reported for deaf signers with less severely restricted early language, although usually not at the basic clausal level (Boudreault & Mayberry, 2006; Cormier et al., 2012; Henner et al., 2016; Newport, 1990).

Robust use of linguistic cues such as basic word order can be better demonstrated when the syntactic cue (i.e., word order) conflicts with the semantic cue (i.e., world knowledge), as in ASL sentences like "BANANA BITE BOY"[1] (meaning a banana bites a boy), given the basic subject-verb-

[1]Following ASL research convention, we use capitalized English words as ASL glosses.

object (SVO) word order of ASL. On a sentence-picture verification task, late L1 signers with more than nine years of ASL experience tended to use world knowledge instead of word order when comprehending implausible events, resulting in below chance performance in the implausible conditions (Cheng & Mayberry, 2021). Furthermore, animate subjects did not induce increased use of canonical word order in the implausible events. Still, in this study, subject animacy did not change the animacy hierarchy conflict in implausible sentences, as the patient role was mostly a human, with a higher animacy hierarchy rank than the animate agent that was mostly an animal. Nouns with a higher rank in the animacy hierarchy (e.g., human > animal > inanimate objects) are often more likely to be the agent of the event. Therefore, it is less clear whether late L1 signers use animacy to assign thematic roles when there is no conflict in the animacy hierarchy.

The findings to date suggest a weaker development of linguistic representations at the basic clausal level when language learning begins after early childhood. Meanwhile, the nature of late L1 signers' linguistic capacity at the basic clausal level remains unclear. It is possible that late L1 signers show an overall strong preference for plausible events and/or animacy hierarchy given their early life experience without a formal language, independent of their linguistic capacity. Testing implausible sentence comprehension using other basic clause structures that late L1 signers perform well on can shed light on this question. Based on Mayberry et al. (2023), two basic clause structures appear to be fully comprehensible by most late L1 signers: nouns with intransitive verbs or adjectives; and spatial classifier constructions specifying the locative relations between two static entities. The former only requires the linguistic composition of one entity and its attributes, while the latter requires an iconic mapping of the spatial relation between two entities (Emmorey, 2002; Emmorey & Tversky, 2002; Karadöller et al., 2021; Martin & Sera, 2006; Morgan et al., 2008). Furthermore, if late L1 learners have a strong preference for plausible events, testing transitive sentences that are implausible and non-reversible (implausible even when the semantic roles are reversed) can reveal their actual use, or weighting, of ASL basic word order and animacy in comprehension of the transitive SVO structure.

In the current study, we examine the comprehension strategies (plausibility, animacy, linguistic cues) used by late L1 ASL signers at the basic clause level to reveal the role of early language experience on early syntactic development. More specifically, we ask two questions: 1) Does real-world knowledge always influence late L1 signers' comprehension of basic clause linguistic structures? 2) Do late L1 signers rely on animacy and/or word order to comprehend implausible, irreversible transitive SVO sentences where real-world knowledge is not available?

Methods

Participants

Nine late L1 ASL signers participated in the current study. We conducted interviews with each signer multiple times to learn about their language background. These interviews were less structured and more tailored to each participant, as the unique language background of each late L1 signer requires individualized follow-up questions. The first author, a proficient hearing ASL signer with many years of experience working with late L1 signers and had already worked with some of the participants in the past, conducted the participant background interviews, with the help of their language teachers and/or family members. All nine signers are bilaterally profoundly deaf from birth and never used hearing aids (except for LS3, who had been using hearing aids since age 27). They all had limited access to any spoken/written and sign language before they became fully immersed in a Deaf community that provided a natural ASL environment, and they all currently consider ASL as their main communication tool, with limited spoken/written language use. Five signers (LS1-LS5) have hearing, non-signing parents, with no deaf siblings. Four signers (LS6-LS9) are from the same household with hearing parents and siblings, and all reported using homesign gestures to communicate with each other as well as with other hearing family members before they formally learned ASL. All except for LS4 are immigrants from other countries, where early intervention for deaf children was not available. LS4

Table 1. Demographic and language background of each deaf late L1 signer (LS1-LS9) and the deaf native signers as a group (NS, N = 12).

Signer	Gender	Age at testing	Age of sign exposure	Years of sign exposure	Deaf family members
LS1	M	19	15	4	None
LS2	M	24	13	11	None
LS3	M	42	13	29	None
LS4	F	53	11	42	None
LS5	M	57	21	36	None
LS6	F	19	11	8	older siblings
LS7	M	26	19	7	younger and older siblings
LS8	M	30	23	7	younger and older siblings
LS9	F	32	25	7	younger siblings
Native signers (NS, *N*=12)	7 F	43.27 (12.31)	birth	Same as age	At least one parent

was born in the U.S. but did not attend school until age 11. LS1, LS3, LS4, and LS6 learned ASL in deaf schools or deaf and hard-of-hearing programs in the U.S., while LS2, LS5, LS7, LS8, and LS9 learned ASL mainly through social services (e.g., deaf group homes, small ASL classrooms for immigrants, etc.) and interactions with the deaf community. We also included 12 deaf ASL signers who acquired ASL at home from birth from deaf, signing parents as a comparison group (Native Signers, NS). Table 1 summarizes the demographic and language information of the deaf participants.[2]

Task design, materials, & procedures

We developed a sentence-picture matching task to examine the sentence comprehension strategies used by native and late L1 signers. We provided two pictures as alternatives instead of just one in a picture verification task to avoid the occasional yes-bias observed in Cheng and Mayberry (2021). Each trial began with a 1000 ms focus cross followed by a short video clip showing a deaf native signer signing an ASL utterance. Next, two pictures appeared on both sides of the screen, one corresponding to the previous ASL utterance, and the other to a minimally contrastive meaning. The task was to press one of the keys (one on the left, one on the right) to select the picture that matched the ASL utterance. The ASL video clip was shown only once and disappeared before the pictures appeared. Response accuracy for each trial was recorded for analysis. The order of trials was pseudorandomized to avoid any back-to-back sequence of identical structures, and the location of the matching pictures was counterbalanced as well. To reduce the working memory burden given the relatively short working memory span of late L1 signers (Mayberry et al., 2023), all ASL utterances consisted of three lexical signs for the intransitive/adjective and transitive conditions and two lexical signs with one spatial classifier construction for the spatial classifier construction. All ASL utterances lasted about 3000 ms.

First, we included two basic clause linguistic structures that are fully comprehensible for late L1 signers based on previous studies: nouns with intransitive verbs or adjectives; and classifier constructions denoting spatial relations between two entities. For nouns with intransitive verbs or adjectives, we included both the Adjective-Subject-Verb construction (e.g., SMART ELEPHANT READ) and the Adjective-Adjective-Subject construction (e.g. BIG RED APPLE), as successful comprehension of both constructions requires combining the corresponding entity and the attributes. ASL classifier constructions denoting spatial relations consist of two lexical signs (e.g., CUP and APPLE) and the use of a simultaneous classifier construction that shows the relative spatial relation between the two entities (Emmorey, 2002), for example a classifier with the handshape open-5 indicating an apple on top of a classifier with the handshape C indicating a cup (see Figure 1c for the ASL illustration). For these

[2]Previous case studies have reported LS2's language (Cheng & Mayberry, 2019; Ferjan Ramírez et al., 2013) and brain (Cheng et al., 2019; Ferjan Ramirez et al., 2014, 2016) development. Previous studies have reported LS5's neural functional (Mayberry et al., 2018) and anatomical (Cheng et al., 2019) results. Three signers (LS2, LS4, LS5) have also participated in previous experiments on ASL sentence comprehension (Cheng & Mayberry, 2021; Mayberry et al., 2023).

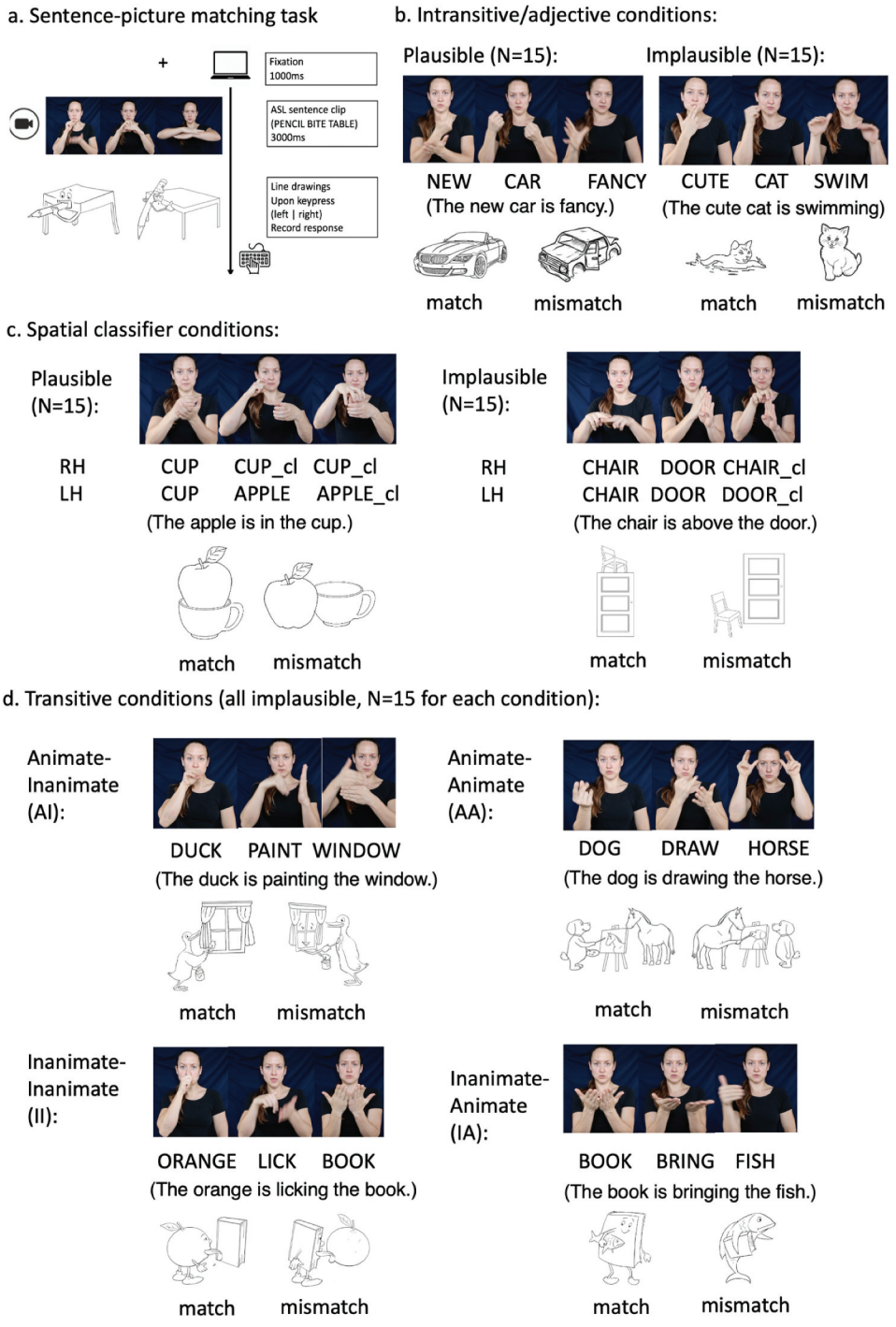

Figure 1. Task procedures (1a) and examples of each condition (1b-d). cl – classifier. RH – right hand. LH – left hand.

conditions, we manipulated event probability to examine a possible interaction between event plausibility and linguistic structure. The alternative pictures for the intransitive events changed one element of the combination (either the subject noun, the intransitive event, or the adjectival attribute); the alternative pictures for the spatial relations depicted a different spatial relation between the two entities. For both the plausible and the implausible intransitive/adjectival and spatial classifier construction conditions, the alternative pictures were all plausible. All spatial classifier constructions were signed from the viewer's perspective to reduce the cognitive load of mental rotation (Emmorey & Tversky, 2002; Martin & Sera, 2006; Morgan et al., 2008) and the alternative picture always depicted a different (e.g., beside vs. in front of) instead of an opposite spatial relation (behind vs. in front of). Each condition included 15 items, yielding 60 target items in total.

Next, for the transitive sentence conditions, we included four types of transitive sentences, all consisting of two nouns and one plain verb following the SVO word order in ASL. SVO is considered the basic word order in ASL (Kegl et al., 1996), but multiple word order variations are also allowed, including sentence-final pronominal subject repetition (Padden, 2016) and object topicalization accompanied by mandatory non-manual markers and verb spatial, aspectual, or handling markings (Aarons, 1994; Fischer & Janis, 1990; Hoffmeister, 1978; Kegl, 1976; Liddell, 1980; Matsuoka, 1997; Pichler, 2001). ASL also allows null arguments (Lillo-Martin, 1986), which makes the surface word order variations even more diverse. Regardless of these potential word order variations, however, without additional non-manual markers and pronominal subjects, a Noun-Verb-Noun combination can only be linguistically interpreted as SVO. As evident from the native signers' performance in Cheng and Mayberry (2021) and Miles et al. (2024), basic word order is a highly reliable linguistic cue for proficient ASL signers.

All the transitive sentences expressed implausible meanings that were non-reversible, meaning that the reversed interpretation was also implausible. There were no human characters involved in any events. We manipulated the animacy (animate vs. inanimate) of each noun (subject, object), yielding four sentence conditions: Animate-Inanimate (AI), Animate–Animate (AA), Inanimate–Inanimate (II), and Inanimate–Animate (IA).

Consistent with the previous study (Cheng & Mayberry, 2021), we only included plain verbs that do not have morphological markers and also limited the appearance of other grammatical markers that can influence thematic role assignment in ASL, including non-manual markers and role-shifting. This was to ensure that the basic SVO word order was the only linguistic cue available for thematic role assignment during sentence comprehension. The corresponding picture showed a transitive event following the SVO word order, while the alternative picture showed a transitive event following the reversed, OVS word order. Each condition included 15 items, yielding 60 target items in total. Eight verbs were used in the Animate-Inanimate (AI) and the Inanimate-Animate (IA) conditions, fully matched in type and token: BRING (2), DRAW (2), HUG (2), KICK (2), KISS (2), PAINT (2), PUSH (2), and RIDE (1). The Animate-Animate (AA) condition consisted of seven verbs (some verbs were excluded due to higher event plausibility): BRING (2), DRAW (2), FEED (3), HUG (2), PAINT (2), PUSH (2), RIDE (2). The Inanimate-inanimate (II) condition involved twelve verbs with low plausibility in all combinations: BITE (1), BRING (1), CHASE (2), DRAW (1), FEED (1), HUG (1), KICK (1), KISS (1), LICK (2), PAINT (2), RIDE (1), PUSH (1). Three deaf early signers recruited from the community who were not participants in the experiment rated the plausibility of all ASL sentences on a scale of 1 to 5 (1= fully implausible, 5=fully plausible). We excluded sentences designed to be plausible but elicited an average score lower than 4, and sentences designed to be implausible but received an average score above 2, and replaced those with new sentences.

All ASL stimuli were designed by the hearing, proficient ASL signer authors in consultation with three deaf native signers with ASL research experience and filmed by a deaf native signer. Figure 1 shows the task procedures (1a) as well as examples of the ASL stimuli (static screenshot of each sign with the corresponding English gloss translation) and the picture options for each condition (1b-d).

The sentence-picture matching task was first implemented in OpenSesame (Mathôt et al., 2012) and conducted in full-screen mode on a 13' Mac laptop in person for three late L1 signers (LS2, LS4,

LS5) in 2019. During the COVID pandemic, we adopted an online version of the experiment via Pavlovia (https://pavlovia.org/) with the same procedures. All remaining participants (native and late L1 signers) took the experiment online, with a deaf or hearing proficient signer guiding them during the testing session through Zoom or FaceTime. During the experiment, the participants first performed a practice session with ten plausible intransitive, transitive, and spatial sentences that were different from the actual testing materials to ensure that they understood the task. They received feedback on their picture selection ("correct" vs. "incorrect") during the practice phase. Next, they proceeded to the actual task with 120 trials in two blocks, with randomized item order. They were prompted to take a break after 60 trials. The whole task required about 30 min.

Analyses & predictions

Given that severely delayed language exposure is somewhat rare in North America, this special group sample size is small of necessity. Also, given the vastly different language learning environments and age and years of ASL exposure, they may show substantial individual differences, making it difficult to treat them as a natural group. Therefore, we used a predetermined criterion for our individual-level statistical analysis, in addition to a group-based analysis. A response was considered correct if the participant selected the corresponding picture from the two options, with the chance level of getting the correct answer being 50%. The probability of getting at least 12 out of 15 trials correct by chance was very low ($p = .0175$). Thus, we set an overall accuracy of 0.8 or higher as a pre-determined criterion for statistically significant evidence of consistently relying on linguistic cues during sentence comprehension. Similarly, getting at most 3 out of 15 trials correct by chance was also low, and indicated consistently selecting the alternative picture. An overall accuracy of 0.2 or lower was set as another predetermined criterion for significantly below-chance performance, indicating a consistent reliance on alternative cues in some of the conditions (for example animacy in the transitive IA condition, or plausibility in the implausible spatial classifier condition).

We also built generalized linear mixed models and conducted likelihood ratio tests to examine the statistical significance of our fixed effects (Barr et al., 2013). All models were built in R using the lme package and the Glmer function (D. Bates et al., 2015). Main effects were tested by converting other main effect factors to sum-coding numeric representations and conducting a likelihood-ratio test between mixed-effects models differing only in the presence or absence of the fixed main effect (Levy, 2014).

We first analyzed the known structure conditions to determine how late signers comprehended implausible events when the sentences involved noun-attribute combinations or spatial classifiers. Based on previous research on late L1 signers (Mayberry et al., 2023), we predicted significantly above-chance performance in plausible conditions. For the implausible conditions with learned structures, there were two possibilities. On one hand, late L1 signers may show a strong bias for plausible events regardless of the linguistic materials presented to them. This prediction was consistent with the previous study (Cheng & Mayberry, 2021), which showed a strong reliance on plausibility when late L1 learners comprehended transitive sentences. Given the extended period of time they matured with no formal language use, late L1 signers may rely heavily on their world knowledge over linguistic structure in general. If this were the case, then we would expect lower accuracy in both implausible conditions. Alternatively, late L1 learners may be capable of relying on linguistic structure, but only when the linguistic representations are fully acquired and robust. Previous studies with other less proficient language users often found more reliance on extra-linguistic cues when the sentence structure became more complex (Montgomery et al., 2016; Saffran et al., 1998; Strohner & Nelson, 1974; Thal & Flores, 2001). If this were the case, then we would expect high accuracy in both implausible conditions with learned structures.

For the transitive events, there were several possibilities framed by the stages of typical L1 syntactic development (Abbot-Smith & Tomasello, 2006; Abbot-Smith et al., 2017; E. Bates et al., 1984; Chan et al., 2009, 2010; Chapman & Kohn, 1978; Chapman & Miller, 1975; Strohner & Nelson, 1974; Thal &

Table 2. Predicted outcomes for the transitive conditions based on different comprehension strategies.

Predictions	Comprehension strategies: A(nimate); I(nanimate)	Tran-AI	Tran-AA	Tran-II	Tran-IA
A	Rely on real-world knowledge only	>0.5	chance	chance	<0.5
B	Rely on animacy hierarchy only	>0.8	chance	chance	<0.2
C	Rely on animate agent first strategy	>0.8	>0.8	chance	chance
D	Rely on word order with influence from conflicting animacy	>0.8	>0.8	>0.8	chance
E	Robustly rely on word order	>0.8	>0.8	>0.8	>0.8

Flores, 2001). First, if world knowledge were the only valid cue for transitive sentence comprehension, then we would expect chance-level performance across all four transitive conditions, with slightly higher performance in AI and slightly lower performance in IA, based on the close alignment of animacy and agency in the real world (Prediction A). If animacy hierarchy were the main tool for thematic assignment when world knowledge is unavailable, we would expect chance-level performance in AA and II, but above-chance performance in AI and below-chance performance in IA (Prediction B). Alternatively, late signers may use an animate-agent-first strategy and therefore show higher accuracy only when the agent is animate (Prediction C). The late signers may also achieve relatively resilient word order regardless of the subject animacy, but still show some influence from animacy, resulting in chance-level performance only in the IA condition when animacy conflicts with word order (Prediction D). Finally, if the late L1 signers can robustly rely on word order when it is not masked by world knowledge, then we would expect above-chance performance in all conditions (Prediction E). Table 2 summarizes the expected outcomes based on these predictions.

Results

First, we examined the overall accuracy in sentences with linguistic structures that are known by late L1 signers: nouns with intransitive verbs or adjectives; and spatial classifier structures. As shown in Figure 2, regardless of plausibility, all deaf native signers performed significantly above chance (mean accuracies above 0.93), suggesting robust reliance on linguistic structures. Late L1 signers also showed overall high accuracy in the plausible conditions (Intran/Adj: mean = 0.97, sd = 0.05; Spatial classifier:

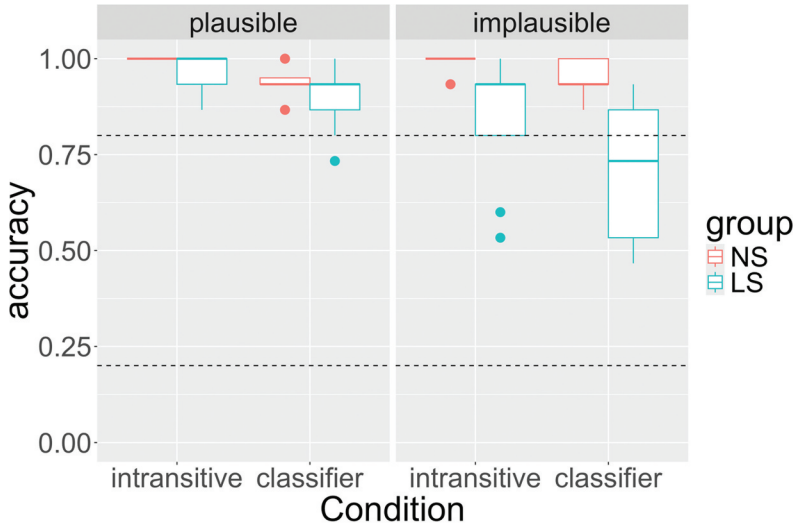

Figure 2. Group comparison between native signers (NS) and late L1 signers (LS) in plausible and implausible resilient structures. The dotted line at 0.8: significantly above-chance performance level (12/15 correct, $p = .0175$). The dotted line at 0.2: significantly below-chance performance level (3/15 correct, $p = .0175$).

mean = 0.89, sd = 0.08). All but one late L1 signer performed significantly above chance (>0.8) in both plausible conditions, replicating the findings from Mayberry et al. (2023). This suggests that the late L1 signers fully understood the sentence-picture matching task and were able to map between the linguistic form and the meaning when the meaning was plausible. As for the implausible conditions, their overall accuracy was high for the intransitive/adjective condition (mean = 0.84, sd = 0.17), and slightly lower for the spatial classifier condition (mean = 0.73, sd = 0.18). The majority of the late L1 signers (seven out of nine) performed significantly above chance (>0.8) when the sentences involved nouns with intransitive verbs or adjectives. However, for the implausible spatial classifier sentences, fewer than half of the late signers (four out of nine) performed significantly above chance. None of the late L1 signers performed significantly below chance (0.2) in either implausible condition.

Using a generalized linear mixed model with item accuracy (correct vs. incorrect) as the dependent variable and group (NS vs. LS), structure (intransitive/adjective vs. spatial classifier) and plausibility (plausible vs. implausible) and the interactions between these three factors as independent variables, and with participant and item as random error terms, we found main effects of group ($\chi^2(1) = 17.57$, $p < .001$), structure ($\chi^2(1) = 14.81$, $p < .001$), and plausibility ($\chi^2(1) = 6.5$, $p = .01$), as well as an interaction between plausibility and group ($\chi2(1) = 5.24$, $p = .02$).

In addition, for the responses by late L1 signers in two implausible conditions, we built generalized linear mixed models with the intercept as the only fixed effect, and with participant and item as random error terms, to estimate their overall performance against chance as a group. The group performance was significantly above chance for the intransitive/adjective condition (Estimate = 2.28, se = 0.59, z = 3.85, $p < .001$) and also for the spatial classifier condition (Estimate = 1.49, se = 0.50, z = 2.96, $p = .003$).

Next, we examined the transitive conditions with implausible irreversible sentences contrasting in subject and object animacy. Figure 3 shows the group comparison of accuracy across all four conditions. Native signers all performed significantly above chance regardless of subject and object animacy, suggesting robust reliance on word order with minimal influence from conflicting animacy. This replicated the findings from Cheng and Mayberry (2021).

As for the late L1 signers, their overall accuracy was higher for the Animate–Inanimate (AI) condition (mean = 0.83, sd = 0.11), slightly lower for the Animate–Animate (AA) condition (mean = 0.77, sd = 0.13)

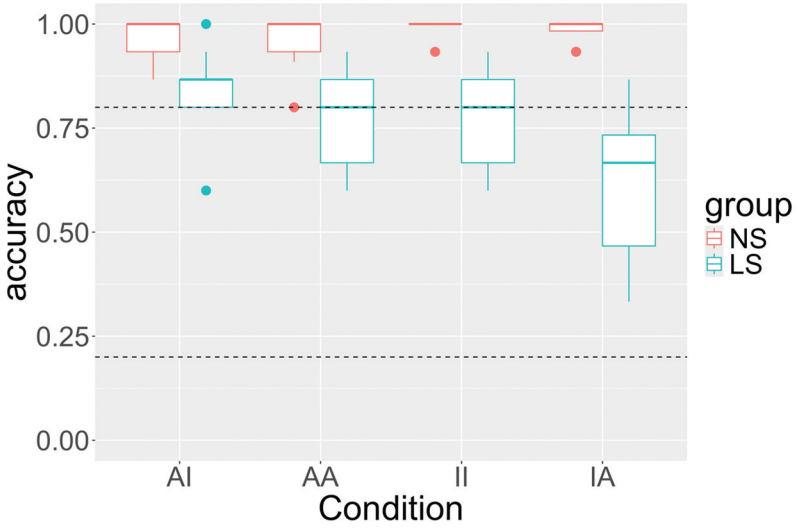

Figure 3. Group comparison between native signers (NS) and late L1 signers (LS) in four implausible transitive conditions contrasting in subject animacy and object animacy. The dotted line at 0.8: significantly above-chance performance level (12/15 correct, p=.0175). The dotted line at 0.2: significantly below-chance performance level (3/15 correct, p=.0175). AI: animate-Inanimate; AA: animate-Animate; II: inanimate-Inanimate; IA: inanimate-Animate.

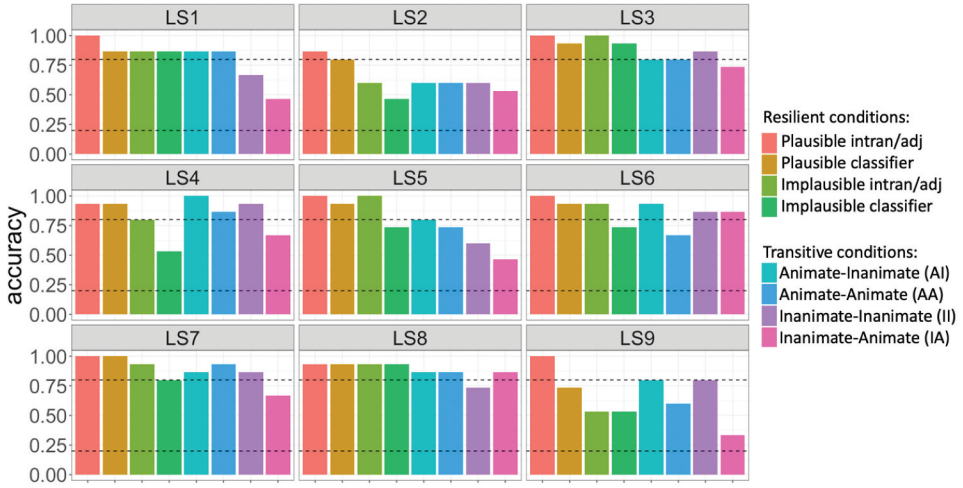

Figure 4. Individual comprehension patterns by late L1 signers. The dotted line at 0.8: significantly above-chance performance level (≥12/15 correct, $p = .0175$). The dotted line at 0.2: significantly below-chance performance level (≤3/15 correct, $p = .0175$).

and the Inanimate–Inanimate (II) condition (mean = 0.77, sd = 0.13), and the lowest for the Inanimate–Animate (IA) condition (mean = 0.62, sd = 0.19). All but one late L1 signer performed significantly above chance for the AI condition, suggesting successful comprehension when there is no conflict between word order and animacy. More than half of the late L1 signers performed significantly above chance for the AA and II conditions respectively. In contrast, the majority of the late L1 signers (seven out of nine) did not perform significantly above chance for the IA condition, indicating influence from animacy on the use of word order. None of the late L1 signers performed significantly below chance (0.2) in any of the transitive conditions.

Using a generalized linear mixed model with item accuracy (correct vs. incorrect) as the dependent variable, and group (NS vs. LS), subject animacy (animate vs. inanimate) and object animacy (inanimate vs. animate) and the interactions among these three factors as independent variables, with participant and item as random error terms, we found a main effect of group ($\chi^2(1) = 35.37$, $p < .001$), a marginal main effect of object animacy ($\chi^2(1) = 3.17$, $p = .07$), as well as an interaction effect between group and subject animacy ($\chi^2(1) = 9.59$, $p = .001$).

For the responses by late L1 signers in each of the transitive conditions, we built generalized linear mixed models with the intercept as the only fixed effect, and with participant and item as random error terms, to estimate their overall performance against chance as a group. Group performance was significantly above chance for the Animate-Inanimate (AI) condition (Estimate = 1.79, se = 0.33, z = 5.40, p < .001), the Animate–Animate (AA) condition (Estimate = 1.23, se = 0.21, z = 5.88, p < .001), the Inanimate–Inanimate (II) condition (Estimate = 1.28, se = 0.29, z = 4.31, p < .001), but not for the Inanimate-Animate (IA) condition (Estimate = 0.51, se = 0.32, z = 1.57, p = .11).

Figure 4 shows the individual patterns of comprehension across all conditions. LS3, LS6, LS7, and LS8 showed above-chance or close to above-chance accuracy across all conditions. LS1, LS4, and LS5 showed some influence from plausibility and/or animacy. LS2 and LS9 showed the strongest influence from plausibility, with chance-level performance in intransitive/adjective and spatial classifier implausible conditions. Still, LS2 performed at the chance level for all transitive conditions, while LS9 performed above chance for AI and II conditions. One important environmental factor to note is that the three younger siblings from the home-signing family all performed close to above chance, while the oldest sibling, LS9, showed overall less robust reliance on linguistic cues.

Discussion

The current study aimed to investigate the nature of late L1 signers' use of linguistic and extra-linguistic cues at the basic clausal level. Specifically, we asked two questions: 1) Does real-world knowledge always influence late L1 signers' comprehension of basic clause linguistic structures? 2) Do late L1 signers rely on animacy or word order to comprehend implausible irreversible transitive events where real-world knowledge is not available?

Turning to our first research question, the majority of the late L1 signers robustly relied on the linguistic cues when the event involved only one entity (nouns with intransitive verbs or adjectives). Fewer late L1 signers performed significantly above chance when the events involved spatial relationships between two entities, even though they could fully comprehend plausible spatial relationships using spatial classifiers, both in the plausible condition in the current study and also in Mayberry et al. (2023). Previous studies on early child language acquisition of ASL (Martin & Sera, 2006) and British Sign Language (BSL) (Morgan et al., 2008) suggested that despite the iconicity during form-meaning mapping, the correct use of spatial classifier constructions during comprehension continues to develop between ages three to five, even when the events do not require perspective shifts or mental rotation. Therefore, it is possible that the late L1 signers also developed a less robust representation of the spatial classifier constructions and are thus influenced by real world knowledge. Still, overall, their performance was above chance as a group. This was very different from the findings on transitive events from Cheng and Mayberry (2021), where the accuracy for implausible transitive events was lower than chance, suggesting a strong reliance on world knowledge over word order. Also, the fact that the late L1 signers were able to pick the corresponding pictures in implausible events suggests that the previously found difficulties in comprehending implausible sentences were not entirely due to conceptual difficulties in integrating implausible meanings (Patson & Warren, 2010). Altogether, these findings suggest that the degree of reliance on world knowledge depends on the robustness of the linguistic structure.

For our second research question, we found overall high accuracy in the AI condition ($M = 0.83$), slightly lower accuracy but above-chance group performance in AA ($M = 0.77$) and II ($M = 0.77$) conditions, and chance-level group performance for the IA condition ($M = 0.62$). In terms of our predictions (see Table 2), these results fit well with the predicted patterns where late L1 signers show word order use with influence from conflicting animacy cues (Prediction D). These results do not support the hypothesis that world knowledge is the only cue available for late L1 signers to assign thematic roles, indicating resilient use of basic word order when it is not masked by real-world knowledge. Nor do the results support the hypothesis that late L1 signers rely mostly on animacy hierarchy, as none of the late L1 signers showed below-chance performance in the IA condition. Furthermore, late L1 signers performed above chance in both AA and II conditions, suggesting that they were not simply adopting an animate-agent-first strategy, but were treating the first noun as an agent in a more abstract fashion. The effect of animacy found in the current study was not found in Cheng and Mayberry (2021) where animacy was confounded with animacy hierarchy. The fact that late L1 signers were able to pick the corresponding pictures in implausible transitive events again indicates that the conceptual difficulties in integrating implausible meanings do not necessarily contribute to low performance in comprehending implausible sentences. Altogether, results from the current study and from Cheng and Mayberry (2021) suggest relatively resilient use of word order by late L1 signers when not influenced by real-world knowledge and animacy, with world knowledge having a stronger influence than animacy.

Late L1 signers' use of word order, animacy, and world knowledge highly resembles the performance of children before three and half years of age as reported in the literature, who also show a strong influence from sentence probability, some influence from animacy, and overall resilient word order use when other cues were not available (Chan et al., 2009, Cannizzaro 2012; Chapman & Miller, 1975; Strohner & Nelson, 1974). No such studies have been conducted with deaf children acquiring ASL from birth, but given the similarities in word order variation and the use of null arguments of ASL

and Cantonese, we can assume they would show comparable performance as Cantonese-speaking children in similar tasks (70% correct by 3 and half years of age in Chan et al., 2009). Also, few studies in the child language literature have examined the implausible Inanimate–Inanimate condition (although there is some evidence that even two-year-olds may perform above chance level (de Villiers & de Villiers, 1973); therefore, it is unclear how late L1 signers compare with younger children. Future studies including young deaf signing children are required to confirm comparisons between late L1 and early L1 development of ASL word order comprehension strategies.

We did observe some individual differences among the nine late L1 signers, consistent with previous findings on late L1 signers (Miles et al., 2024). Performance by LS1, LS4, LS5, and LS7 all fit Prediction D, with resilient use of word order and some influence from animacy and plausibility. These four signers all learned ASL after early childhood, but show variations in terms of their ages of ASL onset (11 to 21 years of age), years of ASL exposure (ranging from 4 to 42 years), and family language environment (three without deaf siblings, one with both younger and older deaf siblings). This echoes previous findings on late L1 signers, suggesting a generally similar developmental trajectory across late L1 signers despite wide environmental differences (Cheng & Mayberry, 2021; Morford, 2003) with a potential early plateau (Mayberry et al., 2023) when a sign language is acquired later in life as the first functional language. Two signers, LS2 and LS9, performed at chance level in both intransitive and spatial classifier implausible conditions, despite their high accuracy in the plausible conditions. LS2 also performed at chance level in all transitive conditions, with no evidence of using animacy or word order when world knowledge is not available. Because their performance in the implausible intransitive and spatial conditions was not below chance, it appears that this signer may be guessing the linguistic meaning instead of fully relying on plausibility when the sentence meaning is implausible. LS9 performed above chance in AI and II conditions, but not in AA and IA conditions. Their accuracy in the IA condition was also the lowest (0.33) among all late L1 signers. Combined with chance-level performance in the implausible intransitive and spatial conditions, this suggests that this signer may have resilient use of word order (based on their performance in the II conditions) that is strongly influenced by both event plausibility and animacy. On the other hand, LS3, LS6, and LS8 all performed relatively well in all conditions including the IA condition. Still, unlike the native signers who showed robust reliance on word order with accuracy above 0.8 all the time, none of the late L1 signers performed above chance in all four transitive conditions.

Three of the younger siblings from the same family (LS6, LS7, LS8) all showed relatively high reliance on word order, while the oldest sibling (LS9) showed strong influence from event plausibility and animacy. Having an older deaf sibling likely increases the frequency of communicative and conceptual input and hence accelerates the development of the family homesign system (German, 2024; Haviland, 2013; Hou, 2016), which may facilitate subsequent learning of a formal sign language. The language environment of the younger siblings also resembles those of the later cohorts of an emerging sign language (Senghas et al., 2004), with early input from a homesign system that evolves over time. Given that young children tend to regularize inconsistent input (Singleton & Newport, 2004), it is possible that each younger sibling added more linguistic regularities to the homesign system, which may in turn support their learning of a formal language, ASL, later in life. Still, the oldest sibling did not benefit from this evolving homesign system, as evidenced by her ASL word order use. Future studies are required to further examine the role of early homesign environment on the later acquisition of a formal sign language.

All four signers who learned from a school setting (LS1, LS3, LS4, LS6) showed relatively more reliance on linguistic cues, while two of the late L1 signers who did not learn from a school setting (LS2 and LS9) showed more influence from plausibility and animacy. It is possible that a school setting provides more explicit language instruction and intervention, which can better support late L1 learning (Ofori-Sanzo et al., 2023). Learning ASL in a school environment may also provide more frequent social interactions that are known to promote language learning in younger children (Kuhl, 2007). The school environment may also support the development of other cognitive functions such as executive functions, which play a role in language comprehension (Woodard et al., 2016). Also,

learning a language in a school setting is typically confounded with the age of ASL exposure, as the age of arrival often dictates whether a deaf immigrant gets placed into the school system or not. Future studies are required to articulate the potential role of learning ASL from a school setting for deaf immigrants with minimal prior language.

Overall, all signers except for LS2 showed some resilient use of word order, and the majority of the signers also showed some influence from event plausibility and animacy. Altogether, findings from the current study suggest that late L1 signers do show some limited use of word order when extra-linguistic cues such as event plausibility or animacy are not in conflict with the linguistic cues. Still, their lower performance in the IA condition when animacy conflicts with word order, together with below chance performance in a previous study when event plausibility conflicted with word order (Cheng & Mayberry, 2021), suggests a weaker representation of linguistic structure at the basic clausal level for transitive events. These findings further provided evidence of the resemblance between early and late L1 development during early syntactic development, as children with diverse language backgrounds before three and half years of age also show similar weak syntactic representation of basic clause structure and are susceptible to influence from event plausibility and animacy.

The current study adds to previous findings from homesign gesturers (Goldin-Meadow, 2005) showing that single argument structures can be relatively resilient to a lack of early language input. However, the subsequent learning of structures with dual arguments is gradient and hence less robust, influenced by world knowledge and to a lesser extent animacy. The results indicate that early language experience is crucial for establishing robust syntactic representation even at the basic clausal level. Combined with previous findings on the overall language outcomes of late L1 signers (Mayberry et al., 2023; Newport, 1990), this study further confirms a plateau in syntactic development at an early developmental stage in the circumstance where first language development is severely delayed. Even though basic clause structure is somewhat resilient to early language deprivation, it is less robust and susceptible to strong influence from extra-linguistic cues. This weak foundation at the basic clausal level may have a cascading effect on processing and learning complex sentence structures (Mayberry et al., 2023), as it will limit the ability to use syntactic bootstrapping (Fisher et al., 2010; Gertner et al., 2006; Harrigan et al., 2019; Naigles, 1990, 1996; Papafragou et al., 2007).

The current study also provides practical implications for deaf children who have experienced insufficient early language. Interventions at the morpho-syntactic level with a focus on basic clause structures may help later learners break through this developmental plateau and continue to develop complex linguistic structures. A recent study using syntax intervention with two deaf children who were acquiring ASL as a late L1 found improvement in their use of basic SVO word order in ASL during elicited production after 6–10 sessions of targeted intervention on this structure (Ofori-Sanzo et al., 2023). Future research is needed to further explore the role of targeted syntax intervention on the comprehension and production of SVO structures as well as other syntactic structures by deaf late L1 signing children and adults.

More online processing research is required to further specify the nature of the less robust reliance on linguistic structures in late L1 signers. From a processing perspective, a less robust syntactic representation likely results in a lower degree of syntactic activation of the target structure, which will lead to occasional reliance on extra-linguistic cues (e.g., plausibility, animacy) during comprehension. On the other hand, other factors associated with early language deprivation may also manifest in the process of sentence comprehension. For example, a lack of early language and/or early schooling may result in lower executive functions (M. Hall et al., 2018), which increases the difficulties of inhibiting the non-target interpretation. Furthermore, their early experience navigating everyday life with minimal language may drive the late L1 signers to show more preference for plausible events during the rational inference process during sentence comprehension (Gibson et al., 2013). Results from the current study and from Cheng and Mayberry (2021) showed that the influence from such preference is subject to syntactic complexity, suggesting an interaction between linguistic and extra-linguistic factors. These mechanisms (linguistic activation of the target structure, inhibition of an alternative interpretation, rationale integration) may occur at different stages of sentence processing,

which cannot be sufficiently distinguished in the current offline comprehension task. Future studies using online processing methods (e.g., via eye-tracking or EEG) and with measurements of other cognitive skills (e.g., executive functions, non-verbal working memory) may be more suitable to disentangle these linguistic and domain-general cognitive mechanisms.

There are some caveats in the current study. Given the low incidence of severely delayed first language acquisition in the U.S., we only gathered data from a small sample. However, in some developing countries, more deaf children have limited access to deaf education, which results in pervasive delays in sign language acquisition. Also, for the transitive events, we only focused on the use of basic word order, while other linguistic cues, such as spatial markers and role shifting may also play a role in thematic role assignment for late L1 signers. Future studies with a larger sample size, with other linguistic cues at the basic clausal level, and on other sign languages are required to confirm the findings.

Conclusion

The current study examined ASL comprehension strategies used by nine deaf late L1 signers as compared to twelve deaf native L1 signers. We found overall above-chance performance when they comprehended implausible sentences involving previously learned resilient structures. Furthermore, we found evidence of word order uses by most late L1 signers when the subject/object animacy did not conflict with word order. Still, the majority of the late L1 signers showed an influence from animacy, as evidenced by their lower performance in the Inanimate-Animate condition. Altogether, these findings suggest a graded representation of linguistic structures at the basic clausal level when a first language is acquired later in life. Early language experience is required for developing robust basic clausal syntactic representations.

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Data availability statement

All data and study materials are available on OSF at https://osf.io/msve8/.

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