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PHONOLOGICAL ANALYSIS

The acquisition of prosody in American Sign Language

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This is the first comparative analysis of prosody in deaf, native-signing children (ages 5;0–8;5) and adults whose first language is American Sign Language (ASL). The goals of this study are to describe the distribution of prosodic cues during acquisition, to determine which cues across age groups are most predictive in determining clausal and prosodic boundaries, and to ascertain how much isomorphy there is in ASL between syntactic and prosodic units. The results show that all cues are acquired compositionally, and that the prosodic patterns in child and adult ASL signers exhibit important differences regarding specific cues; however, in all groups the manual cues are more predictive of prosodic boundaries than nonmanual markers. This is evidence for a division of labor between the cues that are produced to mark constituents and those that contribute to semantic and pragmatic meaning. There is also more isomorphy in adults than in children, so these results add to the debates about isomorphy, suggesting that while there is clear autonomy between prosody and syntax, productions exhibiting nonisomorphy are relatively rare overall.*

Keywords: language acquisition, sign language, prosody, phonology, American Sign Language

1. Introduction. In this article the prosody of American Sign Language (ASL) in native-signing deaf children and Deaf adults is described.[1] There are several reasons why this is important. First, while there is a robust literature on the prosodic system of sign languages (Wilbur 1994, 1999, 2009, Nespor & Sandler 1999, Sandler 1999, 2010, 2012, Wilbur & Patschke 1999, Brentari & Crossley 2002, Sandler & Lillo-Martin 2006, Sze 2008, Pfau & Quer 2010), to date there have been no analyses of how these cues become an adult-like prosodic system during 'later' first language acquisition, that is, from five to eight years of age. Since the development of narrative devices, syntactic devices, and prosodic structure occur autonomously in spoken languages (Allen & Hawkins 1980, Crystal 1986, Snow 1994, 1995, Snow & Balog 2002, Ballard et al. 2012), ASL can serve as a test case in a different modality. Second, this work also adds to our understanding of the ASL prosodic system, in general, by determining which prosodic cues are most robust in child and adult native signers of ASL. Third, ASL can potentially provide evidence from a language in the visual modality about the prosody-syntax interface, and the mechanisms of autonomy and isomorphy frequently at issue in these debates.[2] While there is general consensus that the two components are autonomous and allow nonisomorphy between prosody and syntax, approaches differ with regard to how the interface constraints should be expressed. For example, both in spoken and signed languages some researchers argue for a direct link between prosody and syntax; such theories allow these components to interact directly, and they treat

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[1] Upper case '**D**eaf' is reserved for culturally Deaf individuals and requires enculturation over a long time course; hence even native-signing children will be referred to with a lower case '**d**eaf', which refers to the biological definition.

[2] Nonisomorphy is just one argument in favor of autonomous prosody and syntax. Other relevant issues are whether or not prosodic structure adheres to the strict layer hypothesis or exhibits recursivity, as does syntactic structure.

nonisomorphic cases as exceptions to general principles of alignment. In spoken languages such research would include that by Selkirk (1995, 2011) and Itô and Mester (2011), and in sign languages Petronio and Lillo-Martin (1997), Neidle and colleagues (2000), and Pfau and Quer (2010). The other view maintains that prosody interacts with syntax primarily (or exclusively) indirectly via semantics. In spoken languages this view is held by Pierrehumbert and Hirschberg (1990), Bartels (1999), and Truckenbrodt (2012), and in sign languages Sandler and Lillo-Martin (2006) and Sandler (2010).

The analyses that follow concern the production patterns across a profile of prosodic properties that have been shown to be important for marking INTONATIONAL PHRASES (I-phrases), described in detail in the following sections. Of the three major areas of research with regard to prosody—that is, (i) dividing the stream of words/signs into constituents, (ii) expressing prominence, and (iii) mapping intonational tunes and their meaning—we are concerned here only with the first, namely, how words/signs are divided into constituents. The adult ASL data is used as a baseline against which to compare data from children acquiring ASL as a first language, ages 5;0–8;5 (years;months).

If the time course for the acquisition of prosody is the same for signed and spoken languages, children acquiring ASL as a first language will have different patterns in I-phrases and UTTERANCES than adults. The age group chosen for this study has been shown to be actively engaged in the acquisition of prosodic, narrative, and syntactic structure in spoken languages (Dankovicová et al. 2004, Patel & Brayton 2009, Shport & Redford 2014). From the spoken language literature on the perception of prosody in very early acquisition we know that babies perceive prosodic constituents before syntactic ones, as proposed in the theory of ‘prosodic bootstrapping’ (Nazzi et al. 2000). Despite this early sensitivity to prosody in perception, in production there appears to be an interaction of marked and unmarked structures, and their integration into increasingly larger prosodic and syntactic units is gradual. Between two and four years of age, trochaic and iambic patterns are already seen at the level of disyllabic words (Gerken 1996, Ramus et al. 1999, Gladfelter & Goffman 2013), and some aspects of phrasal intonation have been observed during the syllabic babbling stage at approximately age 1;6 (Snow 1994, Snow & Balog 2002). But Patel and Brayton (2009) found that contrastive stress in questions vs. statements is not stabilized until sometime between four and seven years of age as narrative and syntactic complexity increases. In addition, Dankovicová and colleagues (2004) found considerable variation in phrase-final lengthening for intermediate phrases even in eight-year-olds (e.g. *milk bottles, and chocolate* vs. *milk, bottles, and chocolate*), indicating that at this age the use of prosody to indicate constituent boundaries is still being acquired. Katz and colleagues (1996) also found continuous improvement in the production of I-phrase-final lengthening in five-year-olds, seven-year-olds, and adults. Finally, a study of five-year-old Swedish children both with and without language impairment found a strong correlation between prosodic development, syntactic development, and phonological development (Samuelson & Nettelbladt 2004).

Moving on to the consideration of sign languages, in virtually all aspects of first language acquisition studied to date, the developmental milestones and time course of first language acquisition are the same for hearing children acquiring a spoken language and for deaf children acquiring a sign language (Volterra & Erting 1990, Meier 1991, Lillo-Martin & Crain 1999, Chamberlain et al. 2000, Schick et al. 2006, Chen-Pichler 2012). Thus, if signed and spoken languages behave similarly with respect to the development of prosody at the phrasal level and beyond, the children in our study acquiring ASL natively between 5;0 and 8;5 should be mastering the patterns of prosody in larger units during this period.

The following analyses investigate ASL prosodic cues both individually and grouped into 'manual' cues (those expressed by the hands) and 'nonmanual' markers (those expressed on the face, head, and body; henceforth NMMs) to determine which of these two types is more important for dividing the stream of signing into I-phrases and utterances. Both types are important and can be introduced into the stream of signing in a number of ways, described in the next section.

1.1. Adult ASL prosodic system. The prosodic system of native adult signers has been studied extensively; see Nespor & Sandler 1999, Sandler 1999, 2010, 2012, and Pfau & Quer 2010 for good overviews. Using the prosodic hierarchy proposed in Nespor & Vogel 1986, specific properties of the prosodic word, the phonological phrase, the I-phrase, and the utterance have been proposed for sign languages (Wilbur 1994, 1999, 2009, Wilbur & Patschke 1998, 1999, Nespor & Sandler 1999, Sandler 1999, Brentari & Crossley 2002, Nicodemus 2010, Tang et al. 2010, Brentari et al. 2011, Brentari et al. 2012). The definition of an I-phrase in sign languages is taken from Nespor and Vogel's (1986) definition (Nespor & Sandler 1999): parentheticals, nonrestrictive relative clauses, topicalizations, and other types of extraposed elements are associated with I-phrases, but the domain also depends on rate of production (Nespor & Sandler 1999, Wilbur 1999).

Prosodic cues include some properties of movements for which parallels can be found in spoken languages. Word duration and sign duration are similar in both modalities (Wilbur 1999), peak velocity of movement is similar to frequency (Limousin & Blondel 2010), and displacement of movement is similar to intensity (Wilbur 1999). NMMs such as blinking, torso leans, and the position of brows, head, and body have been suggested to be similar to the intonational tunes of speech; Sandler and Lillo-Martin (2006) call the NMMs 'superarticulation'. The cues to which we devote our attention have been shown to be important for marking I-phrases and utterances not only in ASL but also crosslinguistically (Nespor & Sandler 1999, Sze 2008, Hermann 2010, Tang et al. 2010), although there are language-particular differences in the overall distribution of some cues.

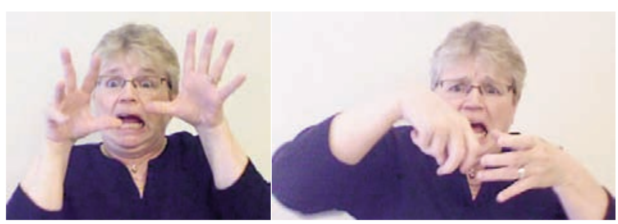
There are seven primary cues associated with I-phrases. The three manual cues are sign lengthening (Nespor & Sandler 1999, Wilbur 1999), pause lengthening (Grosjean & Lane 1977), and holds (Liddell & Johnson 1989, Perlmutter 1992). The NMMs associated with I-phrase boundaries in ASL are inhibited, periodic eye blinks (Wilbur 1994), changes in the position of the brows (Liddell 1980, Brentari et al. 2011), recalibration of body position (Boyes Braem 1999), and recalibration of head position (Nespor & Sandler 1999, Nicodemus 2010). These last two involve a return to neutral position from a lean (in the case of body position) or from a head tilt or head nod (in the case of head position). The techniques for measuring these cues are explained in the transcription and measurements section. The cues for utterance boundaries are more exaggerated lengthening strategies in signs and pauses, plus a generalized recalibration of the whole body (Nespor & Sandler 1999, Nicodemus 2010).

A previous experimental study using a binary, forced-choice task to determine the importance of each cue in determining I-phrase boundaries (break; no break) showed that ASL signers depend the most on pauses to identify I-phrase breaks, and the lack of a hold to identify the absence of a break (Brentari et al. 2011). Note that both pauses and holds are manual cues. With regard to NMMs, Sandler and Lillo-Martin (2006) argue that, even though some NMMs have a syntactic role in Israeli Sign Language and ASL, NMMs are always realized over a prosodic rather than a syntactic or morphological domain. If this is the case, NMMs will also be important for marking I-phrases and utterances in production, even if they are not the most important cues for the perception of these boundaries.

NMMs from four different sources may potentially assume a prosodic role, and three of these have the potential to spread to the domain of the I-phrase. The first type are those NMMs tied to particular signs, such as occur in ANGRY and SCARED (Figure 1).[3] Crucially, the articulation of these signs is judged to be ungrammatical without these NMMs, and they have the potential to spread to domains larger than the sign, as seen in Fig. 1.

[Ø] ANGRY 2-vehicle-chase

(He) is angry and the two vehicles chase each other.

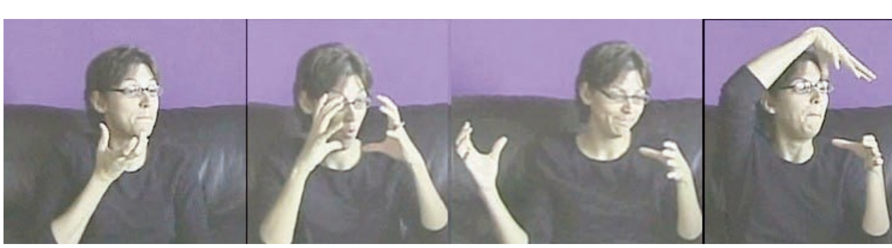


[Ø] SCARED runs-around-cage

(He) is scared and runs around the cage.

FIGURE 1. NMMs associated with specific signs: (top left) ANGRY and (bottom left) SCARED. These are NMMs involving the whole face. Importantly, these NMMs can spread across the whole I-phrase in each case, as shown in the two-sign sentences illustrated here.

NMMs of the second type have a syntactic function; one example is eyebrow raise, used for topic constructions (Liddell 1980, Wilbur & Patschke 1999), conditionals (Reilly et al. 1990b), and relative clauses (Liddell 1980) in ASL. An example is shown in Figure 2—an eyebrow raise indicating the topic cooccurring with the signs BOWLING BALL. This cue is componential because the meaning is associated with the eyebrows only.



_______________topic/brow raise

BOWLING BALL CARRY DROP

. . . you know, a bowling ball, (he) got it and dropped it.

FIGURE 2. Compositional use of eyebrow raise accompanying a topic-structure sentence initially; BOWLING BALL is the topic.

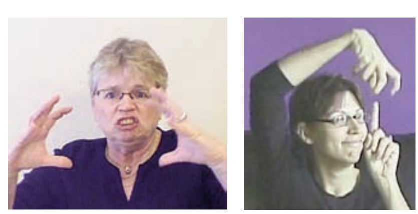
[3] The notational conventions used in this article are as follows. Glosses for ASL signs are given in upper case (e.g. ANGRY). English translations, when needed, are give in italics (… *as for the bowling ball*). Meanings for morphemes or signs are given in single quotations (e.g. 'with ease').

NMMs of the third type occur in ASL during 'role shift', sometimes called CONSTRUCTED ACTION or CONSTRUCTED DIALOGUE structures (Metzger 1995; see Figure 3). Role shift is a device for articulating events through the point of view of a character other than the signer (Lillo-Martin 1995, Quer 2005), similar to such devices for spoken language described by Clark and Gerrig (1990). Role shift occurs in a wide range of quoted contexts, including quotes of propositional content, character affect, and even the actions of a character (Schlenker 2003, Davidson 2015).[4] The meanings associated with these forms are attributed to the whole face (and often the body as well), and like the lexical NMMs in Fig. 1 are not compositional. In Fig. 3 the whole facial expression exhibits the monkey character, who is mesmerized by the banana being offered to him.

_______________________________________CA/brow raise
MONKEY LOOK gaze follows 'long-thin-object' FOLLOW
The monkey looks at it, follows the banana with his eyegaze, then follows behind (it).

FIGURE 3. Noncompositional use of eyebrow raise in role shift.

NMMs not considered in this analysis are those of the lower face. Even though lower-face NMMs can also be compositional, they are typically associated with the domain of the prosodic word rather than the I-phrase or utterance (Wilbur 2000, Brentari & Crossley 2002). There are productive morphemic forms of this type, such as the form glossed as *cha* to mean 'large' or *mm* (lips pressed together) to mean 'with ease' (Figure 4). They are also seen in the mouthing of [b] in *bowling* and [a] in *ball* in BOWLING BALL (Fig. 2; Boyes Braem 2001).



(large) BALL climb-up-pipe (with ease)

FIGURE 4. NMMs associated with the lower face. These cues are not included in our analysis because their domain is the prosodic word. ASL examples are the adjectival morpheme known as *cha*, meaning 'large' (left), and the adverbial morpheme with lips pressed together *mm*, meaning 'with ease' (right).

[4] Constructed action has been documented in many sign languages, among them ASL (Padden 1986, Quinto-Pozos 2007, Quinto-Pozos & Mehta 2010), Danish Sign Language (Engberg-Pedersen 1993, 1995), British Sign Language (Morgan 1999, 2006), Catalan Sign Language (Quer 2005), French Sign Language (Cuxac & Sallandre 2007), Italian Sign Language (Zucchi 2004, Mazzoni 2009), Nicaraguan Sign Language (Pyers & Senghas 2007), Quebec Sign Language (Poulin & Miller 1995), and Swedish Sign Language (Ahlgren 1990, Nilsson 2010).

Sandler and Lillo-Martin (2006) focus on compositional NMMs, but it would seem plausible that, given their semantic and syntactic importance, the NMMs accompanying single signs or role shift would also potentially provide raw material for the prosodic system as well. The three types (Figs. 1–3) are included in this work as potential sources of prosodic NMMs at the level of the I-phrase or utterance.[5]

1.2. Previous work on acquisition and predictions. Very little is known about the acquisition of prosodic elements in ASL in later acquisition, particularly with respect to production at the clausal/phrasal level. To our knowledge this is the first analysis of its kind. Thus far the work on the production of prosody by child signers has focused on early acquisition, largely at the syllable level or at the one- and two-word stage. One movement is equivalent to one syllable in sign languages (Brentari 1998). Petitto and Marentette (1991) and Petitto and colleagues (2004) argue for syllabic babbling in infants exposed to sign, and Meier (2006) and Meier and colleagues (2008) have examined what they call 'proximalization' of sign movements in infants 0;8 to 1;5 (transfer of the movement to a joint more toward the midline of the body). Limousin and Blondel (2010) followed the prosody of two infants acquiring French Sign Language (LSF) between 0;8 and 2;1—one deaf, and one hearing acquiring both French and LSF—and found parallel development in French and LSF at the one- and two-word stage. None of this work addresses clauses or I-phrases longer than two signs.

Thanks to work undertaken by Reilly and colleagues over the last few decades, however, the general time course of the production of NMMs in ASL morphosyntax has been well documented during first language acquisition (Reilly et al. 1990a,b, Reilly 1992, 2000, 2001, Reilly et al. 1994, McIntire & Reilly 1996, Emmorey & Reilly 1998). This work has established three principles with regard to NMMs and ASL grammar. First, the system is acquired compositionally; that is, each NMM is acquired on its own time course according to its role in the grammar. Second, when a structure has both a manual component and an NMM to express the same meaning, the manual component appears first. Third, first language acquisition of ASL exhibits a U-shaped curve composed of three stages of NMM acquisition: appearance, reanalysis/reorganization, and mastery. For example, Reilly and colleagues (1991) noted that deaf children start using eyebrows grammatically in the first half of their third year. Three- and four-year-olds produce conditionals exclusively with the manual component, even if they have previously used raised eyebrows for asking questions, and only at 7;0 and later do they imitate and produce conditionals with both manual and nonmanual components with the correct timing. As for role shift, there is some debate about when this device is mastered in ASL by native-signing children. Children as young as 2;0 produce some instances of role shift (Schick 2006), but children as old as 8;0 still have not mastered this mechanism (McIntire & Reilly 1996).

Based on research from the spoken language literature and that of Reilly and colleagues described above, the specific predictions with respect to the use of cues at the level of the I-phrase and utterance are as follows: (i) prosodic cues will be acquired compositionally; (ii) manual prosodic cues of sign lengthening, hold, and pause lengthening will be acquired earlier and be more robust than NMMs; and (iii) some cues that are present in children will not have adult-like distribution.

[5] Under this system only those paralinguistic expressions that convey the attitude of the signing narrator would not be coopted by the prosodic system (e.g. mouth turned down or smiling to indicate how the signer felt about the event while signing *He did not show up!*).

2. Methods.

2.1. Participants. The eleven participants in this study are two younger children (5;0–6;1; one male, one female), five older children (7;8–8;5; three males, two females), and four adults (age thirty-five to fifty-eight; one male, three females). They are all native signers—that is, born deaf and had parents who were culturally Deaf and used ASL as their primary language of communication.[6] At the time of testing, all of the children were attending the Indiana School for the Deaf in Indianapolis, Indiana, a bilingual, bicultural program. The four adults were from Chicago and Indianapolis. The children's sessions took place either in the child's home or at school. The adult sessions took place either in the participant's home or in the sign language linguistics laboratory of the first author. Narratives were collected one time from all participants, except for the younger male child, from whom narratives were collected at both 5;0 and 6;1.[7]

2.2. Task and procedures. The task consisted of a narrative description of the Sylvester and Tweety cartoon 'Canary Row'. The cartoon depicts various instances of the cat, Sylvester, trying to catch the bird, Tweety. The participants watched the cartoon in its entirety, then the seven short episodes of the cartoon were presented one at a time, and after each the participant would narrate it. For a prosodic analysis of I-phrases it is essential to have long passages of continuous signing, and so three of the longer episodes were selected for analysis here. The child narratives were signed to a fluent, hearing signer who was familiar to the children (two different individuals in successive years), and the adult narratives were told to a single hearing native signer.

2.3. Transcription and measurements. The video files of the narratives (thirty frames per second) were transcribed using ELAN (EUDICO Linguistic Annotator; Crasborn & Sloetjes 2008). Prosodic cues (seven total), I-phrases, utterances, role shifts, and sentence structure were transcribed and analyzed; the cues and their short definitions are given in Table 1, which is described further below. The tiers that did not require grammatical knowledge were annotated by a group of second language learners of ASL moving frame by frame through the video (tiers 1–7, Table 1). One coder was responsible for each of the tiers—sign durations, transitions, holds, blinks, brow position, head position, and body position—seven coders in all. All of their annotations were then checked by either a hearing native signer or by a Deaf early learner of ASL. Annotations concerning prosodic constituency were completed independently by three proficient signers. Two had learned ASL at seven and eight years of age, respectively, and one was a full-time certified interpreter. There was 92% and 90% agreement for utterances and I-phrases before discussion, respectively; the forms on which there was disagreement were resolved after discussion.

The manual cues that were annotated are as follows. Sign duration is the time period from the frame where the first handshape of the sign is fully formed until the first frame when the final handshape of the sign begins to relax or to change to the handshape of the next sign or to rest position (Brentari et al. 2011).[8] A period was deter-

[6] Approval was obtained for this project from the Internal Review Board (IRB) at Purdue University, and all sessions were collected in accord with the policies for the ethical treatment of human subjects, including written consent from adult participants and from the parents of the children.

[7] We attempted to collect narratives from both younger children at ages 4;0, 5;0, and 6;0, which would have resulted in six sessions; however, only three sessions were usable. For both children the attempts at 4;0 were unsuccessful and resulted in just a few sentences of a few signs each. Between 5;0 and 6;0 both children produced usable narratives, and at 6;1 the male produced a usable narrative, but the female's was not usable (i.e. she exhibited a bored demeanor and did not engage with the task).

[8] Sign duration was the measure of the prosodic word, since polymorphemic classifier constructions, and forms created via cliticization, were classified as single signs.

mined as a HOLD if the handshape and exact location were stable for two or more frames (> 33 ms; Liddell 1984). A pause in sign languages typically includes both the sign-final hold (stasis) plus the transition between signs (Grosjean & Lane 1977), but since the sign-final hold is already included in sign duration, TRANSITION DURATION is an independent measure of the notion of pause. Transition duration is therefore used here as the metric for pause duration. A transition is the period from the end of one sign until the beginning of the next, determined by the beginning of the degradation of the one sign's handshape and the full formation of the handshape of the next sign, as described above.

The NMMs annotated for this analysis are as follows; each was also annotated for whether the source of the NMM was a single sign (as in Fig. 1), syntactic in nature (as in Fig. 2), or a role shift (as in Fig. 3). BLINKS are inhibited, periodic blinks that are used for physiological purposes to moisten the eyes. They can be controlled, and they occur at I-phrase boundaries for signers, but not for speakers (Wilbur 1994, Sze 2008, Tang et al. 2010, Brentari et al. 2011, Brentari et al. 2012). These blinks typically last less than 300 milliseconds. Changes in HEAD POSITION and BODY POSITION were annotated according to direction (backward, forward, to the left or right side) and when the signer returned to neutral position (Wilbur & Patschke 1998, Boyes Braem 1999). For the analyses, however, only the count of recalibrations back to neutral position was included because this was the most reliable way to compare this cue across participants.

For the prosodic constituent and sentence annotations, judges were instructed to break the narratives into the largest units, which were labeled utterances, and second largest units, which were labeled I-phrases on a second pass. The judges were linguistically trained, and therefore familiar with the NMMs used for ASL prosody, but were instructed to not use any particular cue to make their judgments. After a first pass at normal speed to divide each episode into utterances, the judges watched each utterance and its boundary four more times: twice at 50% speed using the full screen view, once more at normal speed, and a fifth time with the clips reduced to a 2″ by 2″ square. Each judge contributed one set of judgments after the whole procedure. Signs were then annotated according to mutually exclusive categories as follows (Utt: utterance, IP: I-phrase): Utt-initial, IP-initial, IP-final, Utt-final, and medial (all others).

PROPERTY ANNOTATED	DEFINITION
1. SIGN DURATION	Length of time from full formation of initial handshape to initial decay of final handshape; includes sign-final holds
2. TRANSITION DURATION	Length of time from the end of one sign to the beginning of the next sign
3. BLINKS	Controlled, periodic blinks of 300 ms or less; first indication of the eyes closing until the eyes have completely reopened
4. BROW POSITION	'Neutral', or 'up', or 'down'
5. HOLD	Period of stasis for both the handshape and the location of the hand
6. HEAD RECALIBRATION	Recalibrations toward neutral position
7. BODY RECALIBRATION	Recalibrations toward neutral position
8. I-PHRASES	Strings of sign in the narrative organized into the second largest units
9. UTTERANCES	Strings of sign in the narrative organized into the largest units
10. ROLE SHIFT	Use of the body to indicate words, affect, or actions of a character that are not those of the signer
11. CLAUSES	A predicate and all of its arguments
12. SENTENCES	Syntactically 'simple' (monoclausal) or 'complex' (multiclausal)

TABLE 1. Properties and definitions of the prosodic, syntactic, and narrative cues and units annotated for this analysis.

3. ANALYSIS. The narratives in the following analyses totaled 23 minutes, 773 milliseconds. The average narrative for the younger children was approximately one minute, for the older children approximately two minutes, and for the adults approximately three minutes. The average narrative length by group, as well as the proportion of prosodic cues that originated from lexical items (such as those in Fig. 1), syntax (such as those in Fig. 2), role shift (such as those in Fig. 3), or other, are shown in Table 2. Note that nearly half of the prosodic cues were generated by role shift.

AGE GROUP	MEAN NARRATIVE DURATION	MEAN SIGNS/IP	MEAN IPS/UTT	PROPORTION OF CUES GENERATED BY: lexical items	syntax	role shift	other
Younger children	59 s	4.2	2.9	.24	.16	.43	.17
Older children	116 s	4.7	3.8	.17	.21	.44	.18
Adults	170 s	5.2	5.4	.11	.22	.54	.13

TABLE 2. Key descriptive information about the narratives analyzed. Group means for narrative duration (in seconds), mean number of signs per I-phrase, mean number of I-phrases per utterance, and the source of NMMs.

3.1. PROSODIC CUE DISTRIBUTION. All cues were modeled with mixed-effects regression models, using R and the lme4 package (Bates et al. 2014, R Development Core Team 2014). For all models, the predictors are age (younger children, older children, and adults, with adults as the default group) and phrasal position (Utt-initial, IP-initial, medial, IP-final, and Utt-final, with medial as the default phrasal position), as well as a random effect for subjects. Durational cues of sign duration and transition duration were modeled with mixed-effects linear regression using the log-transformed duration as the outcome, a technique customarily used with data for which values less than zero are not possible, in order to better approximate a normal distribution (see Gelman & Hill 2006 for a description of this technique used with speech data). In a linear regression, positive coefficients indicate an increase in duration relative to the default group or position, whereas negative coefficients indicate a decrease in duration. NMMs and holds were modeled with mixed-effects logistic regression, with the presence or absence of the cue as the outcome (Jaeger 2008). In a logistic regression, positive coefficients indicate that the cue was used more often than the default group or position, and negative coefficients indicate that the cue was used less often. *p*-values for coefficient estimates were computed using the lmerTest package (Kuznetsova et al. 2014). In order for an NMM to be considered aligned with a boundary, it had to occur during the transition between prosodic constituents, within half of the end of the final sign of the previous constituent or within half of the beginning of the first sign of the following constituent.[9] There were 2,017 data points included in each of these analyses.

The overall picture presented in detail in the following specific analyses is that while all cues studied are important for marking I-phrases and utterances in all age groups, there are also differences among the groups. Among the manual cues, transitions and holds show a difference among groups, and among the NMMs, body recalibrations show a difference.

MANUAL CUES. All manual cues were used at IP-final and Utt-final boundaries more frequently than in other phrasal positions in the ages studied; however, older children used holds differently from the other two groups, and younger children used transition cues differently from the other two groups.

Sign duration. IP-final and Utt-final positions showed significantly longer signs than medial phrasal position overall (IP-final: estimate 0.457, *SE* 0.076, $p < 0.001$; Utt-

[9] We realize that the cue strength of holds and NMMs could be annotated in a continuous way (e.g. the length of blink or the degree of lean or head position change); however, cue durations varied considerably from signer to signer, and so for this first step we annotated presence vs. absence. Larger groups of participants would be needed for a continuous analysis of holds and NMMs.

final: estimate 0.650, *SE* 0.093, $p < 0.001$). Utt-initial signs were significantly shorter than those in medial position (estimate −0.203, *SE* 0.090, $p = 0.025$). These results are visualized at the top left of Figure 5.[10]

Transition duration (pauses). IP-final and Utt-final positions had significantly longer transitions than medial phrasal position overall (IP-final: estimate 2.342, *SE* 0.066, $p < 0.001$; Utt-final: estimate 5.252, *SE* 0.086, $p < 0.001$). The younger children also had significantly greater increases in IP-initial, IP-final, and Utt-final transition durations than the other groups (IP-initial × younger children: estimate 0.324, *SE* 0.142, $p < 0.05$; IP-final × younger children: estimate 0.359, *SE* 0.139, $p < 0.01$; Utt-final × younger children: estimate 0.744, *SE* 0.200, $p < 0.001$). Recall that transitions are measured after the sign, so this means that there are longer transitions after initial signs of the I-phrase. These results are visualized at the top right of Fig. 5.

Holds. Holds were treated as 'presence' or 'absence' because a large proportion of forms occurred with no hold at all. IP-final and Utt-final positions had a significantly higher proportion of holds in final position than medial phrasal position overall (IP-final: estimate 0.912, *SE* 0.264, $p < 0.001$; Utt-final: estimate 0.898, *SE* 0.321, $p < 0.01$). The older children had a significantly lower proportion of holds in all phrasal positions relative to the other groups (older children: estimate −1.581, *SE* 0.492, $p < 0.01$). These results are visualized at the bottom of Fig. 5.

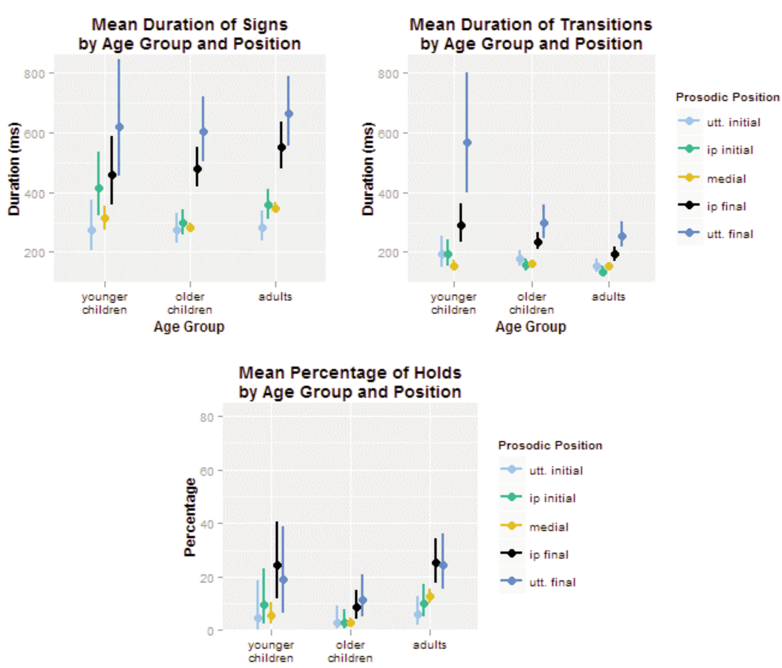


FIGURE 5. Mean sign duration (top left), transition duration (top right), and proportion of holds (bottom) by group and phrasal position. The dots indicate the means and the lines represent 95% confidence intervals. The results for each position are laid out left to right as they would appear in an utterance: Utt-initial, IP-initial, medial, IP-final, and Utt-final.

[10] Figures were created with the ggplot2 package for R (Wickham 2009). The color palette is based on the colorblind-friendly palette given in Chang 2012. Because of computational difficulties in computing confidence intervals for the mixed-effects logistic regression models, all figures with confidence intervals represent estimates and confidence intervals for equivalent models without the subject random effect. The full models are given in the appendices.

Nonmanual cues. All four NMMs were used more frequently in IP-final and Utt-final positions than in other phrasal positions at all ages studied; however, both younger and older children use body recalibrations less often than adults.

Head recalibration. Both IP-final and Utt-final positions had a significantly higher proportion of head calibrations than medial phrasal position overall (IP-final: estimate 0.801, *SE* 0.219, $p < 0.001$; Utt-final: estimate 1.155, *SE* 0.266, $p < 0.001$). These results are visualized at the top left of Figure 6.

Body recalibration. Both IP-final and Utt-final positions had a significantly higher proportion of body calibrations than medial phrasal position (IP-final: estimate 0.470, *SE* 0.237, $p < 0.05$; Utt-final: estimate 0.775, *SE* 0.275, $p < 0.01$). The older and younger children groups both had a lower proportion of body recalibrations overall (older children: estimate −0.509, *SE* 0.189, $p < 0.01$; younger children: estimate −0.909, *SE* 0.339, $p < 0.01$). These results are visualized at the top right of Fig. 6.

Blinks. Utt-initial, IP-final, and Utt-final positions had a significantly higher proportion of blinks than medial phrasal position (Utt-initial: estimate 0.696, *SE* 0.261, $p < 0.01$; IP-final: estimate 0.601, *SE* 0.222, $p < 0.01$; Utt-final: estimate 1.125, *SE* 0.270, $p < 0.001$). These results are visualized at the bottom left of Fig. 6.

Changes in brow position. Both IP-final and Utt-final positions had a significantly higher number of changes in brow position than medial phrasal position (IP-final: estimate 0.753, *SE* 0.253, $p < 0.05$; Utt-final: estimate 1.173, *SE* 0.286, $p < 0.001$). These results are visualized at the bottom right of Fig. 6.

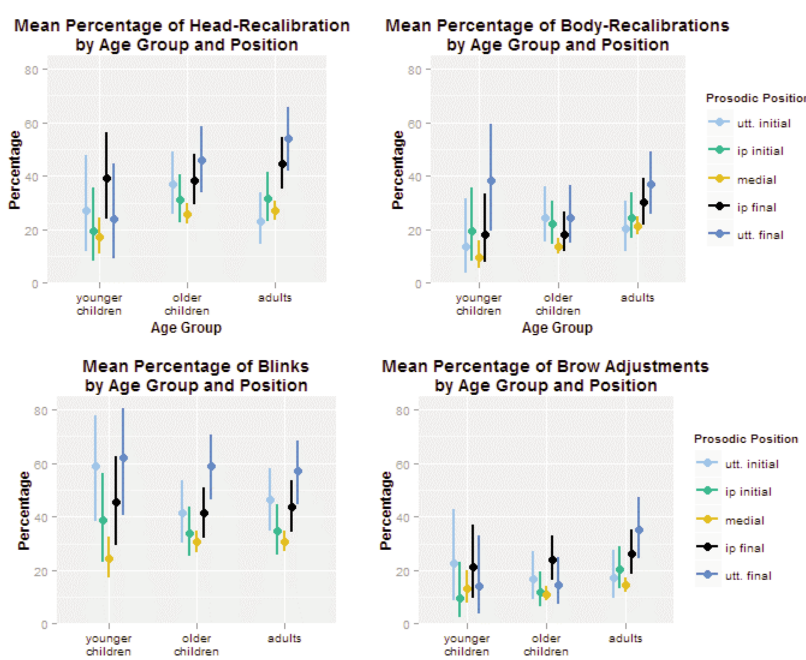


Figure 6. Mean proportion of head recalibrations (top left), body recalibrations (top right), blinks (bottom left), and brow changes (bottom right) by group and phrasal position. The dots indicate the means and the lines represent 95% confidence intervals. The results for each position are laid out left to right as they would appear in an utterance: Utt-initial, IP-initial, medial, IP-final, and Utt-final.

Interim summary. These results show that by 5;0 we can see evidence that children acquiring ASL as a first language mark I-phrases and utterances with both manual cues and NMMs. These results are also in accord with Reilly and colleagues' general findings with regard to compositionality (Reilly et al. 1990b), but they also go a step further. Their work investigated only NMMs, but here we see that all prosodic cues are acquired compositionally, not just NMMs. The children's overall patterns differ from the adults' in a number of ways. Older children use holds less often than the other groups; this is the one place where we see a clear U-shaped curve in evidence. Younger children have longer transitions in several phrasal positions: in IP-initial, IP-final, and Utt-final signs. Body recalibrations (an NMM) are also used less by both groups of children. We might have expected that some cues might show a correlation with a different prosodic domain at earlier stages of development, such as the sign instead of the I-phrase, but this was not supported by the statistical tests.

The effects in initial position are somewhat surprising. Utt-initial signs are shorter and have more blinks after them in all groups, and the younger children have longer transitions after the initial sign in an I-phrase. The shortened initial signs remain a mystery, and future work could investigate whether this is a true shortening effect or an effect of the type of sign that commonly appears in Utt-initial position (e.g. possibly indexical points). The other effects could be due to topics or topicalized signs. Previous work on topic and topicalized structures reported that, while they may constitute a separate I-phrase, they are not obliged to do so (Wilbur 1994, 2009). It may be the case that there was an insufficient number of cues present for the judges to consider these topic structures independent I-phrases. Alternatively, the cues showing an effect after the initial sign might be an indication that they are marking phonological phrases (intermediate phrases), with a break after the subject and before the verb phrase.[11] It may prove difficult to decide between these two explanations without an elicitation task. Table 3 provides a summary of the results.

	SIGN DURATION	BLINK	HEAD RECALIB	EYEBROWS	TRANS MOVEMENTS	HOLDS	BODY RECALIB
Younger children	yes	yes	yes	yes	**no**	yes	**no**
Older children	yes	yes	yes	yes	yes	**no**	**no**

Table 3. Summary of the cue results for the child groups. 'Yes' indicates that the group had a pattern like that of the adults for a given cue; 'no' indicates that the group had a different pattern from the adults.

3.2. Are manual cues more predictive or acquired earlier than NMMs? In this section, we compare the utility of manual cues and NMMs for predicting I-phrase and utterance boundaries across the groups. We did this by comparing the predictive power of statistical models using (i) no cues (using just the raw proportions for prediction), (ii) the NMMs alone (head recalibrations, body recalibrations, eye blinks, and brow adjustments), (iii) the manual cues alone (sign duration, transition duration, and holds), and (iv) all of the cues, both manual cues and NMMs. The goal was to determine whether manual cues or NMMs would be more likely to indicate boundaries broadly construed, so we divided the cues that marked a prosodic boundary (I-phrase or utterance) and those that did not. Since I-phrase-initial cues (those that occur after the initial sign) do not mark a boundary, they were excluded, and we collapsed cues that indicated either I-phrase or utterance boundaries for simplicity, since both mark the boundary of

[11] A referee has suggested that the longer transition after IP-initial signs may also be an attention-getting device.

a constituent. For each age group and set of cues, we computed a logistic regression with the sign position as the outcome variable (medial vs. final). There were 1,601 data points included in this analysis. The details of the analyses below demonstrate that for all groups, we are confident that that the manual cues are better able to predict phrasal position (medial vs. final) than the NMMs, and that the NMMs are better able to predict phrasal position than the raw proportions alone.

In order to compare the predictive capabilities of each model, we used the CORRECTED AKAIKE INFORMATION CRITERION (AICc), a common technique for model comparison (Burnham & Anderson 2002). The AICc value of a model combines a measure of the model's goodness of fit to the data with a penalty term for the number of parameters. In other words, the AICc gives a balanced measure of a model that simultaneously favors describing the data well and minimizing model complexity. The AICc does not give an absolute measure of the data, but is rather a measure that compares related models to each other (i.e. evaluating the models based on a given data set). Importantly, the model with the lower AICc value is the better model based on the data at hand. To compare any of the two statistical models in a pairwise fashion, the difference in their AICc values is computed. The greater the difference between two AICc values (ΔAICc), the more confidence we have that the lower model is significantly better, although Burnham and Anderson are reluctant to use *p*-values.[12] Burnham and Anderson suggest the following rules of thumb for interpreting ΔAICc values: if ΔAICc is between zero and two, we are not at all confident that the model with the lower AICc value is in fact the better model. If the ΔAICc is between four and seven, we have reason to believe that the model with the lower AICc value is the better model, but some doubt remains. If the ΔAICc is greater than ten, we are confident that the model with the lower AICc value is in fact the better model (Burnham & Anderson 2002:70). AICc values were computed using the AICcmodavg package (Mazerolle 2013). The AICc values for each model and group are shown in Figure 7.

Our results show that the model with NMMs is better than the model with no cues (raw proportions) for all three groups; the model with NMMs has the lower value in each case. For younger children, the ΔAICc is 14.2, for the older children 18.1, and for the adults 35.5. We are also confident for all groups that the model with the manual cues alone adds greater predictive power than the model with the NMMs alone. The model with the manual cues has the lower value in all three groups. The ΔAICc is 22.2 in the younger children, 84.9 in the older children, and 40.9 in the adults.

The differences between the model with manual cues alone and the one with all cues are less robust for all groups. All of the group differences between the model with manual cues and the one with all cues fall within Burnham and Anderson's interval of uncertainty and should be interpreted with caution; however, there are some results worth noting. In the adults and younger children the model with all cues has a lower AICc value than the model with just the manual cues; the ΔAICc is 2.0 in the younger children and 4.9 in the adults. This suggests that the manual cues and NMMs may work together to add even greater predictive power than manual cues or NMMs alone. Interestingly, the model order is reversed in the older children. In contrast to the pattern in the younger children and adult groups, for the older children the model with manual cues has a lower

[12] For readers who strongly prefer to think in terms of *p*-values, Murtaugh (2014) gives formulas to convert between AIC differences and *p*-values. These formulas require assumptions that are not met in our case, but they do provide a rough sense of the relationship between AIC differences and *p*-values. An AIC difference of two corresponds to a *p*-value of just under 0.05.

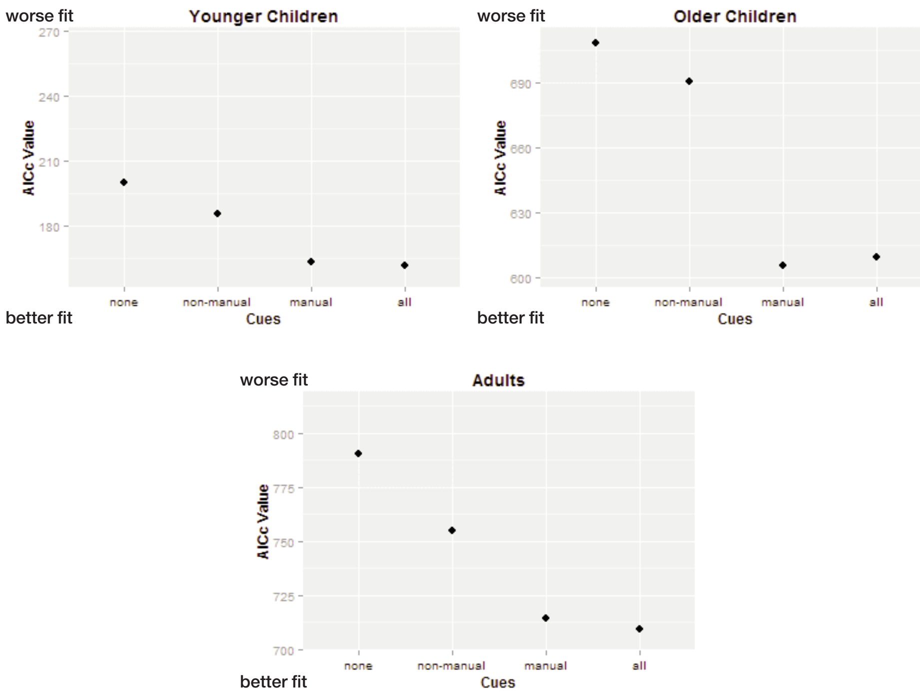


FIGURE 7. AICc values for predicting medial vs. final position (IP-final and Utt-final boundaries collapsed) using: no cues (using raw proportions for prediction), the nonmanual cues alone (head recalibrations, body recalibrations, eye blinks, and brow adjustments), the manual cues alone (sign duration, transition duration, and holds), and all cues. These visualizations use the same scale, but show different areas within it.

AICc value than the model with all cues (ΔAICc is 4.2), suggesting that the model with the manual cues is actually better than the model with all cues. This slight reversal of the order of the two models in the older children (the manual cue model is better than the one with all cues) may indicate that some reorganization of the system is occurring. One possible motivation for this is that the older children are grappling with integrating more complex morphological and prosodic structure. We know that the classifier system of ASL is not mastered until seven or eight years of age (Supalla 1982, Schick 1987, Brentari et al. 2013). While the older children are in the process of gaining mastery over complex classifier constructions, the prosodic cues may become less consistent. Another possible reason for reorganization is the task of integrating greater narrative complexity with prosody in the older children. The number of I-phrases per utterance changes from three (younger group) to four (older children) to five (adults); see Table 2. This added narrative length in older children might be indicative of more complex narrative structure, which may cause the NMMs to become more variable in the older children. This is a topic to be addressed in a future study.

To summarize, we are confident that in all groups the manual cues are better predictors of phrasal and utterance boundaries than NMMs, and that the NMMs are better able to predict phrasal position than the raw proportions alone. When we ask whether the NMMs add anything above the contribution of the manual cues, comparing manual alone vs. all of the cues, the situation is a bit more complicated. For adults and the younger children, the ΔAICc values weakly suggest that the model with both cues is the best model; in other words, the manual cues and NMMs may work together to add predictive power. For older children, the opposite is true: ΔAICc value weakly suggests that the model with manual cues is actually better than the one with all cues—that is, that the NMMs provide some misinformation about where the prosodic boundaries are.

3.3. Isomorphy. The final analysis concerns how much isomorphy is present between prosodic and syntactic constituents at the I-phrase and utterance levels in the three groups. Figure 8 shows the proportion of productions in which a sentence break (simple or complex) corresponds to an I-phrase or utterance at both edges. Notice that isomorphy between prosodic and syntactic breaks increases across groups (younger children 61%, older children 68%, and adults 82%), but even in adults an average of 18% of productions were nonisomorphic. This result is further confirmation of the degree of association vs. autonomy between prosody and syntax in these age groups in the visual modality.

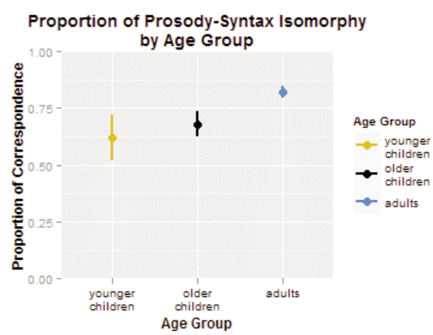


Figure 8. Proportion of sentences that corresponded to a prosodic constituent (I-phrase or utterance) at both the left and right edges for each of the groups. The dots indicate the means, and the lines represent 95% confidence intervals.

4. Discussion. These results have important implications for the prosodic system and the relative importance of manual cues vs. NMMs across age groups. There are also consequences of our findings for the acquisition of the system, and we want to address these findings in light of spoken language acquisition as well. Finally, the results from this data set have some, though limited, implications for the prosodic-syntactic interface in ASL-signing adults and children. In the following sections we address each of these topics in turn.

4.1. Implications for properties of movement in sign language phonology and prosody. The findings presented have implications for sign language phonology in several ways. Movements in sign languages have been argued to function quite similarly to vowels and syllable nuclei in spoken languages. Here we see that the temporal properties of both lexical movements and, surprisingly, transitional movements perform important work in the prosodic system. The manual cues of movement, shown to be important for perception (Brentari et al. 2011), are also more predictive in production than NMMs. Our findings also suggest that all cues are acquired compositionally—not just the NMMs studied by Reilly and colleagues (1990b, 1991), but the manual cues as well; younger children have a different pattern of transitional movements, and older children have a different pattern of holds, than do adults.

In all groups the NMMs are not as predictive of prosodic boundaries as manual cues, and these results support the division of labor proposed by Sandler and Lillo-Martin (2006), who argue that the prosody of sign languages is broken into rhythm, which is carried out by temporal cues as we have confirmed here, and intonation, which is important for semantic and pragmatic meaning. While this is clearly not an absolute division—we see that the NMMs add predictive power—the manual cues are more important for predicting constituent boundaries in ASL across all groups. An additional or alternative explanation for this result is that, while manual cues have a chance to signal a prosodic boundary every single time, the NMMs simply do not appear as often as manual cues. Either way, it would be quite interesting to investigate whether durational cues are acquired before pitch contour cues in spoken languages, particularly those that accompany certain syntactic or semantic meanings. The work on this topic has yielded somewhat disparate results, which are discussed further in the next section.

4.2. Acquisition of prosody in signed and spoken languages. The manual cues are more predictive of prosodic boundaries than NMMs at all ages in ASL, so it is important to ask whether temporal cues are more predictive in spoken languages as well. No one has done an AICc analysis of speech like the one we have done here, and the existing literature on spoken language does not provide a very clear picture on this issue. DePaolis and colleagues (2008) conducted a crosslinguistic study and found that infants acquiring American English, Finnish, French, and Welsh showed evidence that duration (at the level of the word, in this case in the form of syllable-final lengthening) was the first to show language-specific differentiation in production, compared with intensity and fundamental frequency (F0), both of which exhibited higher variability at this stage and no clear crosslinguistic differences. In both imitated and spontaneous speech, Snow (1998) found that monolingual English-speaking children at 2;0 consistently used durational cues phrase-finally (albeit differently from adults), but children continue to develop rising intonation throughout the preschool years. Patel and Grigos (2006) and Patel and Brayton (2009) found differences in question and statement productions in four-, seven-, and eleven-year-olds, and argue that the cues used to signal questions and statements change during development. Younger children more reliably produce the durational cues than F0 contours. Four-year-olds were unable to reliably signal questions using a rising F0 contour, and instead used increased final-syllable duration to mark questions; the seven-year-old group used all three cues to differentiate questions from statements—F0, intensity, and syllable duration—and the oldest group relied primarily on changes in F0 and less on intensity and duration cues. From these studies we might infer that durational cues might be acquired first, but Schwartz and Goffman (1995) found that toddlers (2;0–4;0) differentiate iambic and trochaic words for all three correlates (F0, duration, amplitude).

We can see from the work cited above that acquisition of spoken language prosody continues into the middle school years, so the time course of prosodic acquisition in signed and spoken languages might be best seen through the lens of the three stages: appearance, reorganization, and mastery—not once, but several times as these cues are integrated with increasingly complex morphological, syntactic, and discourse structures. Shport and Redford (2014) found that children aged 6;2–7;3 could maintain duration and intensity for number words in a straight list (thirteen, fourteen), but had difficulty integrating word-stress patterns with phrasal-prominence patterns for both duration and alignment of high tones. In other words, children between 6;2 and 7;3 use both duration and intonational cues correctly in single words but have not mastered their integration into larger prosodic units. The progression from appearance to reorganization to mastery is borne out in the ASL results to some degree. Holds are used less by eight-year-olds than by the other two groups, and the AICc analyses suggest that the NMMs have less predictive power in the older children than in the younger children or in the adults.

The two possible explanations for this appeal to overall structural trade-offs as the system is acquired. It may be that the NMMs become more variable in the older children group while they are in the process of gaining mastery over morphologically complex classifier constructions, or as they begin to use more complex narrative structure (the eight-year-olds' utterances are longer than the four-year-olds'). Longitudinal studies would be necessary to effectively tease apart these two explanations.

We also know that, in the adult prosodic system of spoken languages, cue weighting varies crosslinguistically in perception and production (Cutler et al. 1997, Johnson & Seidl 2008). These language-particular results from ASL need to be seen in that light as well. We know that, while the cues investigated here are reliable crosslinguistically in marking I-phrases and utterances, their cooccurrence at these boundaries can vary. In a study by Tang and colleagues (2010) of Japanese Sign Language (JSL), Hong Kong Sign Language (HKSL), Swiss German Sign Language (DSGS), and ASL, blinks cooccurred more often with head nods at I-phrase boundaries in JSL, while in HKSL, ASL, and DSGS blinks cooccurred more often with lengthening. The colinearity of the prosodic cues studied here is an issue that will be taken up in future work.

4.3. Isomorphy and componential autonomy. It was predicted that there would be some nonisomorphy between syntax and prosody, and our results confirmed this; however, it is interesting to consider the type of isomorphy that was seen in our data. It is well known that a single I-phrase can comprise more than one sentence (e.g. when the two sentences are relatively short, as in {[John entered the room]$_{S1}$ [His heart sank]$_{S2}$}$_{IP1}$[13]) and that a single sentence can comprise more than one I-phrase (e.g. when there are long prepositional phrases, as in [{Mary took a bite of the cake with six layers of buttercream frosting}$_{IP1}$ {and bits of candied fruit on top}$_{IP2}$]$_{S1}$). Almost all of the cases of nonisomorphy from our data are of one of these two types, that is, where an I-phrase break is predictable from syntactic phrase boundaries, but was omitted, or where a single clause included two I-phrases. For example, {BOWLING BALL (topic)}$_{IP1}$ CARRY DROP}$_{IP2}$ {IN P-I-P-E}$_{IP3}$]$_{S1}$, where the break between IP2 and IP3 is not a topic nor a clausal break, and is probably triggered by the longer fingerspelled word P-I-P-E in the following prepositional phrase. Nonisomorphy is more interesting when there is a prosodic break in a location not predicted by syntactic phrases, such as '{John watched} {the girl that ate} {the cake that his wife baked}' (where the breaks are not at CP boundaries) vs. '{John watched the girl}{that ate the cake}{that his wife baked}' (where the prosodic breaks are at CP boundaries). There were only four such instances of prosody-syntax mismatch in the 406 sentences in our data set; this is less than 1% of the data. The data here could be handled by a theory in which there is a fairly close match between syntax and phonology in the default case, and violations are handled by specific constraints (Selkirk 2011).

This study is not the final word, however, because the prosody study presented here addresses only prosodic constituent boundaries. Semantic and pragmatic explanations may turn out to be effective for capturing the range of meanings expressed by a given tone contour in spoken languages or a given NMM sequence in signed languages.

5. Conclusions. This investigation has resulted in several new findings. First, it has added to our knowledge of sign language prosody in adult and child native signers of ASL. The results indicate that children acquiring ASL as a first language demonstrate the

[13] Square brackets [ ] are used to indicate syntactic structure; curly brackets are used for prosodic structure { }.

presence of I-phrase and utterance boundaries by age 5;0 with both manual cues and NMMs. The child prosodic system is also significantly different from the adult system, however—notably in the use of holds (weaker in older children), transition lengthening (stronger in younger children at I-phrase and utterance boundaries), and body recalibrations (less frequent in both groups of children than in adults). It can also be concluded that manual prosodic properties of movement are more important in marking prosodic constituents than NMMs for all of the groups studied here. Besides the theoretical consequences, these results have practical consequences, since annotating all of the prosodic cues manually is extremely time consuming. Progress toward identifying the lexical vs. transitional movements of a string of signs is being made using motion-capture equipment. When this becomes feasible, the results here suggest that such automatically generated output of duration for transitional and lexical movements will be able to provide a good first pass at prosodic parsing. This will allow much more data to be available for deeper analyses of many types.

Returning to the hypotheses from the introduction: (i) the system is acquired compositionally, with respect to both the NMMs, as we expected, and the manual cues; (ii) these findings demonstrate that manual cues are more robust than NMM features at all ages, not just during acquisition; and (iii) regarding a possible shift in the domain of particular cues, the results did not show not a clear shift in domain of cues across the age groups, but rather differences in the overall prosodic pattern. With regard to theories of the prosody-syntax interface, these results suggest that prosodic and syntactic structure are autonomous, but also that in the adult system there is a high degree of isomorphy. Finally, while these results are specific to ASL, they suggest that prosodic acquisition in signed and spoken languages is similar in its time course of acquisition and, importantly, that the adult ASL prosodic system cannot be assumed when handling child data.

APPENDIX A

Mixed linear regressions for each prosodic cue treated continuously—sign duration, transition duration, hold duration (MEDIAL is the default position; ADULT is the default group; see text for further details).

SIGN DURATION:	ESTIMATE	*SE*	*df*	*t*-VALUE	Pr(>|*t*|)
(intercept)	5.87085	0.07970	8.10000	73.663	9.93e-13 ***
Positionip_final	0.45680	0.07565	1994.50000	6.039	1.85e-09 ***
Positionip_initial	0.02363	0.07724	1994.00000	0.306	0.7597
Positionutt_final	0.64963	0.09263	1993.80000	7.013	3.18e-12 ***
Positionutt_initial	−0.20292	0.09016	1993.80000	−2.251	0.0245 *
Groupolder	−0.19726	0.10909	8.70000	−1.808	0.1051
Groupyounger	−0.16277	0.14682	10.30000	−1.109	0.2927
Positionip_final:Groupolder	0.05953	0.10791	1997.30000	0.552	0.5812
Positionip_initial:Groupolder	0.01249	0.10993	1996.90000	0.114	0.9096
Positionutt_final:Groupolder	0.09064	0.13379	1995.00000	0.677	0.4982
Positionutt_initial:Groupolder	0.16923	0.13014	1995.20000	1.300	0.1936
Positionip_final:Groupyounger	−0.12541	0.15896	1997.20000	−0.789	0.4302
Positionip_initial:Groupyounger	0.21860	0.16117	1996.70000	1.356	0.1751
Positionutt_final:Groupyounger	0.01247	0.19177	1994.40000	0.065	0.9482
Positionutt_initial:Groupyounger	0.05112	0.18775	1994.80000	0.272	0.7854

TRANSITION DURATION:	ESTIMATE	*SE*	*df*	*t*-VALUE	Pr(>|*t*|)
(intercept)	5.069e+00	9.565e-02	8.100e+00	52.991	1.41e-11 ***
Positionip_final	2.342e-01	6.594e-02	1.963e+03	3.551	0.000392 ***
Positionip_initial	−1.272e-01	6.706e-02	1.963e+03	−1.897	0.057959
Positionutt_final	5.252e-01	8.536e-02	1.963e+03	6.152	9.24e-10 ***

TRANSITION DURATION:	ESTIMATE	*SE*	*df*	*t*-VALUE	Pr(>|*t*|)
Positionutt_initial	1.306e-02	7.827e-02	1.963e+03	0.167	0.867470
Groupolder	−8.498e-03	1.297e-01	8.400e+00	−0.065	0.949304
Groupyounger	−4.322e-02	1.713e-01	9.200e+00	−0.252	0.806311
Positionip_final:Groupolder	1.649e-01	9.389e-02	1.965e+03	1.757	0.079116
Positionip_initial:Groupolder	1.304e-01	9.546e-02	1.965e+03	1.366	0.172127
Positionutt_final:Groupolder	1.056e-01	1.272e-01	1.963e+03	0.830	0.406625
Positionutt_initial:Groupolder	1.000e-01	1.130e-01	1.964e+03	0.885	0.376145
Positionip_final:Groupyounger	4.382e-01	1.382e-01	1.965e+03	3.171	0.001541 **
Positionip_initial:Groupyounger	2.787e-01	1.400e-01	1.964e+03	1.991	0.046604 *
Positionutt_final:Groupyounger	7.351e-01	1.993e-01	1.963e+03	3.689	0.000232 ***
Positionutt_initial:Groupyounger	1.855e-01	1.630e-01	1.963e+03	1.138	0.255283

APPENDIX B

Mixed logistic regressions for the cues treated categorically—holds, head recalibration, body recalibration, blinks, and eyebrow position (MEDIAL is the default position; ADULT is the default group; see text for further details).

HOLDS:	ESTIMATE	*SE*	*z*-VALUE	Pr(>|*z*|)
(intercept)	−2.0540	0.3131	−6.561	5.35e-11 ***
Positionip_final	0.9124	0.2644	3.450	0.00056 ***
Positionip_initial	−0.2274	0.3592	−0.633	0.52664
Positionutt_final	0.8983	0.3214	2.795	0.00519 **
Positionutt_initial	−0.8561	0.5322	−1.609	0.10771
Groupolder	−1.5810	0.4915	−3.217	0.00130 **
Groupyounger	−1.0996	0.6729	−1.634	0.10225
Positionip_final:Groupolder	0.2562	0.5101	0.502	0.61547
Positionip_initial:Groupolder	0.2586	0.7319	0.353	0.72385
Positionutt_final:Groupolder	0.5580	0.5771	0.967	0.33357
Positionutt_initial:Groupolder	0.9053	0.9264	0.977	0.32846
Positionip_final:Groupyounger	0.6873	0.6280	1.094	0.27374
Positionip_initial:Groupyounger	0.7116	0.8087	0.880	0.37889
Positionutt_final:Groupyounger	0.4446	0.7588	0.586	0.55799
Positionutt_initial:Groupyounger	0.5432	1.2164	0.447	0.65519

HEAD RECALIBRATION:	ESTIMATE	*SE*	*z*-VALUE	Pr(>|*z*|)
(intercept)	−1.02269	0.16323	−6.265	3.72e-10 ***
Positionip_final	0.80079	0.21923	3.653	0.000259 ***
Positionip_initial	0.23102	0.23628	0.978	0.328189
Positionutt_final	1.15497	0.26612	4.340	1.43e-05 ***
Positionutt_initial	−0.20346	0.30014	−0.678	0.497851
Groupolder	0.00106	0.22917	0.005	0.996309
Groupyounger	−0.53199	0.34718	−1.532	0.125440
Positionip_final:Groupolder	−0.19785	0.31677	−0.625	0.532242
Positionip_initial:Groupolder	0.03449	0.33805	0.102	0.918725
Positionutt_final:Groupolder	−0.25054	0.38581	−0.649	0.516093
Positionutt_initial:Groupolder	0.73482	0.40989	1.793	0.073019
Positionip_final:Groupyounger	0.43034	0.48783	0.882	0.377699
Positionip_initial:Groupyounger	−0.02262	0.56913	−0.040	0.968300
Positionutt_final:Groupyounger	−0.70149	0.62897	−1.115	0.264721
Positionutt_initial:Groupyounger	0.85047	0.61792	1.376	0.168721

BODY RECALIBRATION:	ESTIMATE	*SE*	*z*-VALUE	Pr(>|*z*|)
(intercept)	−1.32307	0.11904	−11.114	< 2e-16 ***
Positionip_final	0.46962	0.23651	1.986	0.04708 *
Positionip_initial	0.18453	0.25479	0.724	0.46891
Positionutt_final	0.77542	0.27545	2.815	0.00488 **
Positionutt_initial	−0.05927	0.31518	−0.188	0.85082
Groupolder	−0.50871	0.18871	−2.696	0.00702 **

BODY RECALIBRATION:	ESTIMATE	*SE*	*z*-VALUE	Pr(>|*z*|)
Groupyounger	−0.90893	0.33902	−2.681	0.00734 **
Positionip_final:Groupolder	−0.12270	0.37130	−0.330	0.74105
Positionip_initial:Groupolder	0.39319	0.37514	1.048	0.29459
Positionutt_final:Groupolder	−0.05078	0.42641	−0.119	0.90521
Positionutt_initial:Groupolder	0.78924	0.44686	1.766	0.07736
Positionip_final:Groupyounger	0.24991	0.59389	0.421	0.67389
Positionip_initial:Groupyounger	0.61244	0.60380	1.014	0.31043
Positionutt_final:Groupyounger	0.96641	0.60899	1.587	0.11253
Positionutt_initial:Groupyounger	0.43730	0.76041	0.575	0.56524

BLINK:	ESTIMATE	*SE*	*z*-VALUE	Pr(>|*z*|)
(intercept)	−0.83644	0.23370	−3.579	0.000345 ***
Positionip_final	0.60124	0.22092	2.722	0.006498 **
Positionip_initial	0.19684	0.23314	0.844	0.398510
Positionutt_final	1.12454	0.26991	4.166	3.1e-05 ***
Positionutt_initial	0.69573	0.26112	2.664	0.007713 **
Groupolder	0.13757	0.32022	0.430	0.667492
Groupyounger	−0.37687	0.44069	−0.855	0.392457
Positionip_final:Groupolder	−0.14526	0.31787	−0.457	0.647686
Positionip_initial:Groupolder	−0.06905	0.33408	−0.207	0.836262
Positionutt_final:Groupolder	0.11714	0.39333	0.298	0.765836
Positionutt_initial:Groupolder	−0.20534	0.38102	−0.539	0.589944
Positionip_final:Groupyounger	0.30717	0.46760	0.657	0.511239
Positionip_initial:Groupyounger	0.43770	0.48781	0.897	0.369568
Positionutt_final:Groupyounger	0.49803	0.56956	0.874	0.381894
Positionutt_initial:Groupyounger	0.79826	0.55261	1.445	0.148595

BROW POSITION:	ESTIMATE	*SE*	*z*-VALUE	Pr(>|*z*|)
(intercept)	−1.83477	0.20229	−9.070	< 2e-16 ***
Positionip_final	0.75260	0.25313	2.973	0.00295 **
Positionip_initial	0.41769	0.27672	1.509	0.13120
Positionutt_final	1.17287	0.28557	4.107	4.01e-05 ***
Positionutt_initial	0.21442	0.33891	0.633	0.52695
Groupolder	−0.23905	0.29019	−0.824	0.41008
Groupyounger	−0.07774	0.40889	−0.190	0.84922
Positionip_final:Groupolder	0.17790	0.37256	0.477	0.63301
Positionip_initial:Groupolder	−0.34541	0.43937	−0.786	0.43178
Positionutt_final:Groupolder	−0.86615	0.48351	−1.791	0.07323
Positionutt_initial:Groupolder	0.26026	0.49626	0.524	0.59997
Positionip_final:Groupyounger	−0.15694	0.56462	−0.278	0.78104
Positionip_initial:Groupyounger	−0.74874	0.71909	−1.041	0.29777
Positionutt_final:Groupyounger	−1.06170	0.73627	−1.442	0.14930
Positionutt_initial:Groupyounger	0.46904	0.66828	0.702	0.48277

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